Constance Smith
from Alice Yates.
June 22nd 1888

COLOURED FLAMES.

CHLORIDE OF STRONTIUM. SALT.

NITRATE OF COPPER. ALCOHOL.

SALTPETRE. NITRATE OF COPPER AND CHLORIDE OF STRONTIUM.

SHORT STUDIES

FROM

NATURE.

BY VARIOUS AUTHORS.

Illustrated.

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Short Studies from Nature.

BATS.

By W. S. Dallas, F.L.S.

Among the sounds which greet the ear of the wayfarer as the shades of evening deepen into night, one of the commonest is a rather faint chirping noise which comes mysteriously from overhead. On looking up in search of the source of this peculiar sound, we may see a small, dark, shadow-like creature sweeping to and fro with great rapidity. It is one of the curious group of animals called Bats, representatives of which are to be met with in all countries, always active at night or in the twilight, and presenting a remarkable general similarity of structure, although in some respects they may differ considerably in habits. In the British Islands some fourteen species have been distinguished.

Like the owls, with which they share the dominion of the evening air, the Bats have a perfectly noiseless flight; their activity is chiefly during the twilight, although some species are later, and in fact seem to keep up throughout the whole night. As they rest during the day, concealed usually in the most inaccessible places they can find, and are seen only upon the wing, their power of flight is their

most striking peculiarity in the popular mind, and it is perhaps no great wonder that by many people, both in ancient and modern times, they have been regarded as birds. Nevertheless, their hairy bodies and leathery wings are so unlike anything that we ordinarily understand as pertaining to a bird, that opinion was apparently always divided as to the true nature of these creatures—"a mouse with wings," as Goldsmith called it once, according to James Boswell, is certainly a curious animal, and very difficult to classify so long as the would-be systematist has no particularly definite ideas to guide him. The likeness of the Bat to a winged mouse has made itself felt in the name given to the creature in many languages, such as the "Chauve-souris" of the French and the "Flitter-mouse" of some parts of England, the latter being reproduced almost literally in German, Dutch, and Swedish (Fledermaus, Vledermuis, Flädermus), while the Danes call the Bat a "Flogenmues," which has about the same meaning; and the Swedes have a second name, "Lädermus," evidently referring to the texture of the wings, as well as to the mouse-like character of the body.

But so soon as we have definite characters to appeal to in classification, we find no difficulty in assigning these puzzling creatures to their proper place in the system. Bats produce their young alive, and suckle them; the milk being produced by special glands. Now, these are characters which are peculiar among all animals to the vertebrate class Mammalia. They possess also other characters that are unmistakably mammalian. Leaving out of consideration the structure of the internal

organs, they have teeth implanted in sockets in the jaws, four limbs, and a hairy covering to the skin, so that they possess more decidedly mammalian characters than some other members of the class, such as the marine whales and dolphins (*Cetacea*) and manatees (*Sirenia*), which are still often spoken of as fishes. In point of fact, although organised for flight, the Bat may, without any violence to language, be spoken of as a *quadruped*, for its fore-limbs contain all the parts found in those of other mammals fully developed, and they come into use when the creature is walking on the ground.

Perhaps the special characteristics of the Bats will be brought out most distinctly by a comparison of their structure with that of a bird, seeing that the modification of the fore-limbs into wings is their most striking distinction from other Mammalia; for, although some other members of the class are spoken of as "flying," such as the Flying Squirrels, Flying Lemurs, and Flying Phalangers, these creatures do not really fly, but merely glide through the air to considerable distances by the action of a broad fold of skin which runs down each side of the body, and which, when stretched between the extended limbs, buoys the creatures up in the air after the fashion of a parachute.

Most of us must have had occasion to pick the bones of a bird's wing, a piece of practical anatomy which may serve us in good stead at present. They consist of a long bone, which may be called the arm-bone (*humerus*), jointed to the shoulder-bones (the so-called "side-bones" of a fowl or turkey), followed by a pair of parallel bones con-

stituting the fore-arm, at the end of which we find two or three small bones, then two parallel bones united at their extremities, and some smaller joints terminating the whole.

We need say nothing about the arm-bone and the two bones of the fore-arm, the peculiarity of bird-structure lying chiefly in the terminal portion of the limb, or the hand. Here we find, after two little bones forming the wrist, a pair of long bones as above described, firmly united both at base and apex, and on the outside of the base of these, close to the wrist, a small bone, which may be either free or soldered to the others, and which represents the thumb in the human hand. At the other end of the piece formed by the two united bones, the limb is continued by two joints, forming a second finger, inside of which there is usually a single small bone, representing a third finger. But all these parts are stiffly attached to one another, admitting of very little motion, so that the whole hand forms as it were a single piece. The bony structure of the bird's wing is in point of fact a rod hinged in two places, at the elbow and the wrist, for the convenience of being folded into a small compass. The flight of the bird is effected by the agency of a number of stiff feathers implanted in the skin covering the bones and muscles of the arm and hand; these fold together like the sticks of a fan when the wing is folded, and are spread into an elastic instrument for striking the air when the different sections of the bony framework are extended by the action of their respective muscles.

In the Bat the structure is very different. Of course,

as in the Vertebrata generally, we find in the Bat's fore-limb the same three main sections as in birds; and as the function of the limb is the same, and a certain stiffness is necessary in the extended organ, the movements of the joints at the elbow and wrists are hinge-like. But the bones of the arm and fore-arm are longer and more slender, especially the latter; and in this part, in place of the two parallel bones of the bird's wing, we find in the Bat only a single long bone representing the smaller bone of the bird, the larger one being usually reduced to very small dimensions, and firmly united with the other into a single piece, although it still forms the elbow-joint. At the other end of this long fore-arm we find some small wrist-bones, and to these the fingers are articulated. In birds, as we have seen, only two or three fingers are represented, and these are more or less reduced in size and the most important of them soldered together; Bats, on the contrary, show the whole five fingers as distinctly as in the hand of man or any other mammals. The first of them, or the *thumb*, is short, slender, and flexible, and composed of three joints; the other four are very long and slender, but chiefly composed of the metacarpal bones, corresponding to those of the palm of the human hand. The first, or index finger, indeed, in many Bats, consists of this bone alone; but in the others it is followed by two or three slender joints, gradually tapering to the extremity, the second finger, corresponding to our middle finger, being always the longest of all.

Just as in the bird's wing, these various parts can be folded together or extended by the action of the muscles,

but in the Bat the long fingers become separated when the wing is stretched out, and by this action they at the same time stretch a thin leathery double membrane in which they are enclosed, which is thus converted into a broad surface for striking the air in flight. This membrane is continued from the fingers to the sides of the body, and even to the hind limbs, which are often included in it to the ankle-joints; while in the great majority of Bats there is even a further portion of membrane between the hind legs, enclosing the whole or a portion of the tail. There is usually also a narrow strip of the same membrane in front of each arm, so that the skin of the animal is extended as much as possible, in order to give it support in its aërial evolutions. It is to be noted that the long second finger extends to the extreme point of the wing, and that the first finger runs close beside it, and thus assists in stiffening that part of the organ. The thumb is left free, and is furnished with a rather strong hooked claw.

Supported by the action of these great leathery wings, the Bat flies about almost incessantly during the twilight, and often late into the night. In full career its flight is swift, though perfectly noiseless, and it has the power of executing rapid turns and changes of direction with the greatest facility, as required for the capture of its prey, which, in the great majority of cases, consists of the insects of various kinds that in most places fly by night. In pursuit of these, the Bats flit rapidly about trees, houses, and other buildings, now and then resting by clinging for a moment to the rough surfaces of the walls or the trunks

and branches of trees. Old country churchyards, which are usually full of trees, are naturally favourite haunts of these nocturnal insect-hunters, offering them an excellent field for the chase of their prey, while at the same time, the church itself, with its architectural peculiarities, usually affords them a safe retirement during the day in the dark and secluded corners of its structure. Hence in the popular mind the Bat has long been associated with the churchyard, that spot so dreaded that few can pass through it after nightfall without experiencing certain peculiar feelings, so that it is no great wonder if a portion of the superstitious fear thus engendered has transferred itself to these frail and harmless creatures, and given them and their companions, the owls, something of an evil reputation. And it must be confessed that when seen against the light, flitting silently overhead, there is something weird in the Bat's form, and this is no doubt the reason why, while angels of all kinds are represented with birds' wings, those of Bats have, by universal consent, always been conferred upon demons, dragons, and similar uncanny creatures.

When it descends from its flight upon the ground or any solid body, the Bat becomes to all intents and purposes a genuine quadruped. The fingers being drawn together, with the membranes of the wings thrown into folds between them, the whole hand of the creature is brought up parallel to the fore-arm, and so got out of the way, and the animal can then walk more or less easily, its hind legs, though short and rather feeble, being perfectly formed, and the fore limbs, from which the thumbs with their sharp claws now project freely, becoming available for

terrestrial progression. Nevertheless, this progression is generally rather clumsy, as indeed might be expected from creatures so curiously constructed.

While on the wing, our Bats are constantly engaged in

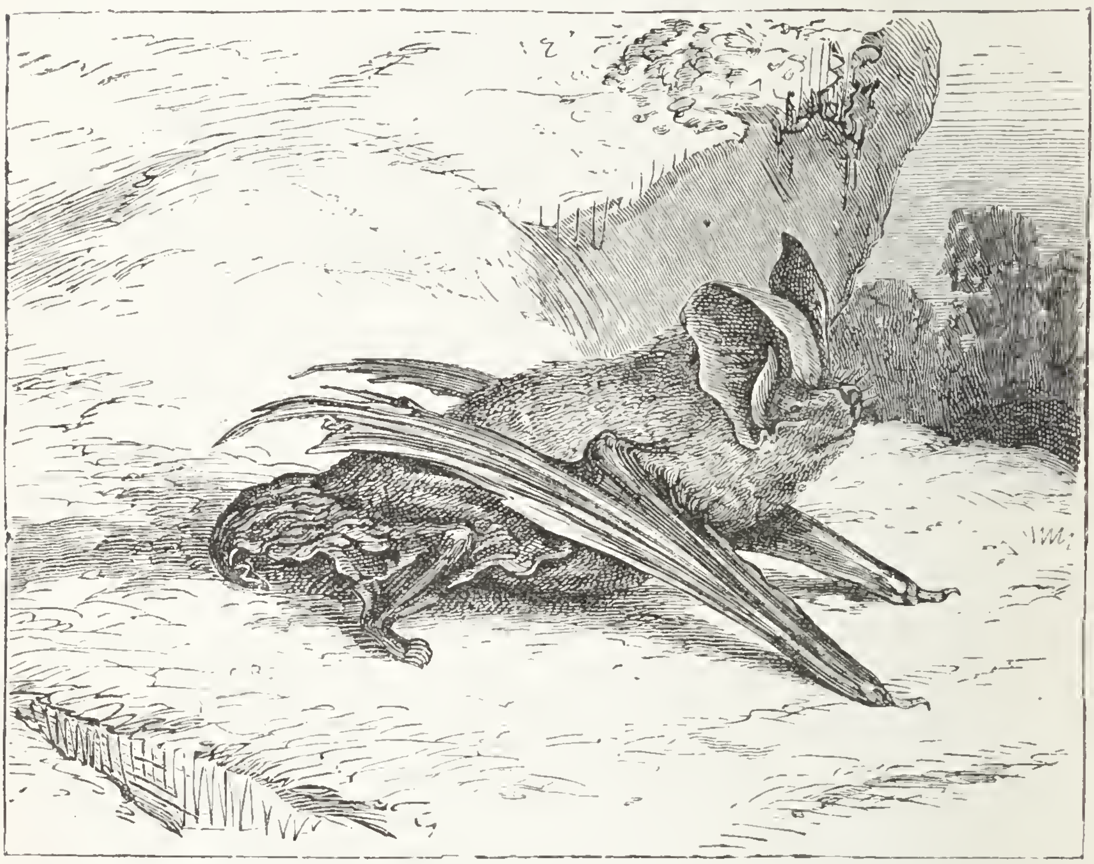

FIG. 1.—BAT WALKING.

the pursuit of the numerous insects of various kinds which, like themselves, are active in the evening and after dark, and of these they must destroy immense quantities. The swarms of delicate gnats and midges which disport themselves in the most complicated aërial dances, moths of all kinds, and even the hard-shelled beetles, many of which fly about in the evening or at night, fall a prey to

these leathern-winged rovers of the night air, and weak as the latter would seem to be, some of them are able to seize and devour beetles which appear to be far beyond their powers. Thus, the largest of our British species, the Great Bat, or Noctule (*Scotophilus noctula*), which, however, is only about three inches in length, preys freely upon such large and hard-shelled insects as cockchafers; these, in fact, appear to be its favourite food, and for their consumption its broad and comparatively strong jaws would seem to be specially fitted, while its large and powerful wings, measuring fourteen or fifteen inches from tip to tip when expanded, enable it to fly with the rapidity necessary for the pursuit and capture of such powerful prey. When thus engaged, the Noctule haunts the neighbourhood of trees, and generally flies at a considerable elevation, from which, however, his shrill cry easily reaches the ear of the passer-by. His addiction to large prey gives rise to a curious movement, thus noticed by Professor Bell in his valuable book on "British Quadrupeds." "An observer will not watch his movements long," says the Professor, "without noticing a manœuvre which at first looks like the falling of a tumbler-pigeon, but on closer examination proves to be simply a closing of the wings, and a consequent drop of about a foot. Sometimes this is repeated every few yards, as long as in sight. It is occasioned by some large and intractable insect having been captured, and the anterior joint of the wing, with its well-armed thumb, is required in retaining it until masticated." Notwithstanding this little difficulty, however, the Noctule is pretty rapid in

disposing even of his most recusant prey, as he has been known to consume as many as thirteen cockchafers one after another.

The foregoing statements apply to all our British Bats, and indeed, in the matter of food and general habits, to the great majority of the species of the order, in whatever country they may occur. But in the tropical and sub-tropical regions of the eastern hemisphere, we find a great and important group of Bats, which, although agreeing in general structure and habits with our European species, differ from them altogether in their diet. These Bats, distinguished generally, among other things, by their larger size and more robust construction, and by certain characters of the molar teeth (grinders), from the ordinary Bats, are almost exclusively confined to a fruit diet, in search of which they fly vigorously, often in flocks, like birds, at the commencement of the night. From this peculiarity of their food they are commonly known as Fruit Bats, while the larger species, such as the Indian Fruit Bat (*Pteropus medius*) and the Kalong (*Pteropus edulis*) of the Eastern Archipelago, which are respectively eleven and fourteen inches in length, are often called Flying Foxes, in allusion to the prevalence of a reddish tint in their fur, and their more or less lengthened and dog-like muzzles. In many parts of the Eastern world, in India, the Malayan Archipelago, Australia, Africa, and even in outlying islands at some distance from their main range, these Fruit Bats occur in great numbers. Swarms of them roost together during the day, hanging from the branches of the trees which they select as their regular

resting-place, and taking wing at sunset, fly off frequently to great distances in search of their favourite articles of food; for they by no means devour indiscriminately any kind of fruit, but show a distinct preference for particular sorts, generally selecting such as are also prized by their human competitors. Hence they often do considerable damage in plantations of fruit trees, as when they meet with articles that suit their taste, they seem, like some human gourmands, not to know when to leave off eating. Of one of the smaller Indian species, the Margined Fruit Bat (*Cynopterus marginatus*), Mr. Dobson obtained a living specimen in Calcutta, and he gives the following account of its voracious appetite:—He gave it "a ripe banana, which, with the skin removed, weighed exactly two ounces. The animal immediately, as if famished with hunger, fell upon the fruit, seized it between the thumbs and the index fingers, and took large mouthfuls out of it, opening the mouth to the fullest extent with extreme voracity. In the space of three hours the whole fruit was consumed. Next morning the Bat was killed, and found to weigh one ounce, half the weight of the food eaten in three hours! Indeed, the animal when eating seemed to be a kind of living mill"—so continuously does its food pass through it.

From the statements of some writers, it would appear that although these Bats live chiefly upon fruits, they occasionally, like many other frugivorous animals, diversify their diet with animal food, devouring insects of various kinds, caterpillars, birds' eggs, and even young birds, while there seems to be some reason to believe that one

species even feeds upon shell-fish which it picks up upon the sea-shore.

The fruit-eating Bats of this group are not found in the warmer parts of America, but some American Bats feed chiefly upon fruits, while many of the large essentially insectivorous species which occur there vary their diet more or less with fruits, and also occasionally attack and devour other vertebrate animals. Some of them—but it is still very doubtful how many—have another habit connected with their feeding, which renders them very decidedly objectionable, namely, that of inflicting wounds upon birds and mammals, even including man himself, and sucking up the blood that flows from them. This charge has been brought against many Bats of South and Central America, some of which have been commonly named "Vampires" in consequence, after the ghostly blood-suckers, which were formerly the objects of so much superstitious terror in Hungary and other parts of Eastern Europe; but so far as can be made out from a consideration of the evidence, a verdict of "not proven," at all events, must be arrived at in the case of all but two species, which constitute a little group distinguished by what is apparently a special organisation adapting them to this peculiar diet. These wretched little beasts, which only measure two-and-a-half or three inches in length, are furnished in the upper jaw with a single pair of incisor or front teeth, but these are of great size and strength, triangular in form, and so excessively sharp that when the creatures are seized they can draw blood from the hand of their captor by what seems a mere touch. This extreme

sharpness of their weapons enables them, when attacking sleeping men or animals, to slice off a small portion of skin almost without causing any pain, and the little oval wounds thus produced, like the similar surface-cuts which a careless shaver sometimes inflicts upon his chin, bleed with particular freedom. The Desmodonts, as these true Vampires are called, will attack horses, mules, and cattle, which they generally wound on the back, near the spine, often in the region of the withers; and they also bite the combs of domestic fowls, and any part of the human body that they can get at. In the case of man, however, according to most authorities, the extremity of the great toe is the favourite part; and some writers, perhaps possessed of a strong poetical vein, have given wonderful descriptions of the artfulness with which these little blood-suckers make their approaches, and keep their victim comfortably asleep during the operation by fanning him with their wings. In fact, the Vampire Bats had so bad a reputation from the accounts given by travellers, that they seemed to be veritable scourges of the countries in which they live, but so far as can be made out from the most trustworthy reports, the mischief they cause may be summed up under two heads, namely, weakness produced by loss of blood, which continues to flow from the wounds

FIG. 2.—SKULL AND DENTITION OF DESMODONT.

long after the Bats have drunk their fill and gone quietly home to rest, and inflammatory affections, caused either by the irritation of the bite in the case of peple of a bad habit of body, or by the friction of the saddle or collar upon the part bitten in the case of horses and mules, or of the shoe in the human patient. That the Desmodonts do really feed on blood is proved by evidence of various kinds. They have been captured in the act of blood-sucking; their stomachs, which are peculiarly constructed and very long, are found filled with a black paste, which is evidently half-digested blood; and their teeth, which are in part so well adapted for producing the necessary wounds in other animals, are totally unfit for the mastication of an insect prey, such as constitutes the diet of their nearest allies.

After all this feeding, Bats, whatever the nature of their diet, not unnaturally find themselves inclined for repose, and as they are active during the night or in the twilight, of course their rest has to be taken in the day-time. To pass the period of repose in security they seek shelter of various kinds, not only for protection against the weather, but also for the sake of concealment from other predaceous animals, some of which would no doubt be perfectly willing to make a meal of them. The great Eastern Fruit Bats, trusting perhaps to their size and strength, are content to resort to the branches of trees, from which, after the manner of Bats in general, they suspend themselves by the hind feet with the head downwards. From the statements of various writers it appears

that after being out all night in search of food, the Flying Foxes and other allied Bats fly back to their regular resting-place, where they begin to arrive about or soon after dawn. The number resorting to the same retreat is usually so great that the whole of the branches are loaded with them, and in fact they are so crowded together that the settling down of the flock into their repose is preceded by a scene of squabbling and quarrelling of the most noisy description. Mr. Tickell, speaking of the common Indian Flying Fox (*Pteropus medius*), says:—"From the arrival of the first comer, until the sun is high above the horizon, a scene of incessant wrangling and contention is enacted among them, as each endeavours to secure a higher and better place, or to eject a neighbour from too close vicinage. In these struggles the Bats hook themselves along the branches, scrambling about hand over hand with some speed, biting each other severely, striking out with the long claw of the thumb, shrieking and cackling without intermission. Each new arrival is compelled to fly several times round the tree, being threatened from all points; and when he eventually hooks on, he has to go through a series of combats, and be probably ejected two or three times, before he makes good his tenure." This scene of selfish contention over, the Fruit Bats pass some hours in profound sleep, during which they remain suspended in rows along the branches, to which they cling by one foot only, the other with all the lower surface of the body being comfortably wrapped in the leathery mantle formed by the contracted wings. In this condition, as Dr. Horsfield says of the Great Kalong (*Pteropus edulis*),

"ranged in succession with the head downwards . . . and often in close contact, they have little resemblance to living beings, and by a person not accustomed to their economy are easily mistaken for a part of the tree, or for a fruit of uncommon size suspended from its branches." In this position the head is folded down upon the breast. Dr. Bennett and Mr. Gould ascribe very similar habits to a large Fruit Bat common in the northern parts of New South Wales and in Queensland, which is said to be often exceedingly destructive to the peach and other fruit crops of the settlers in those colonies.

Our European Bats, and indeed all the Bats except these Flying Foxes and their immediate allies, seek a different kind of shelter. Their chief natural dormitories consist of hollow trees and the caves and fissures of rocks, to which they often resort in great numbers; but in populous countries they also find an abundance of convenient places of retirement in and about buildings of various kinds. Roofs, especially when covered with tiles, or otherwise provided with apertures through which the space immediately under the roofing is easily accessible, out-buildings of all kinds, church towers and other similar structures, disused chimneys, the spaces behind weather-boards and shutters which are not often moved, in fact, any dark and sheltered places about our buildings, are readily resorted to by many species, although some few retain their taste for unadulterated nature so strongly that no artificial harbour will serve their turn. Thus among our British species the Great Bat or Noctule (*Scotophilus noctula*), a generally distributed though not abundant species throughout the

southern and middle counties of England, seems generally to retreat for its diurnal sleep to the holes or cavities in the trunks of trees, and only to visit buildings when there is a scarcity of such accommodation; and the Horse-shoe Bats (*Rhinolophus ferrum-equinum* and *hipposideros*) show a decided preference for caverns and deserted quarries; but the great majority appear to be indifferent in the matter, and to resort to any shelter that seems convenient to them. Some, such as the Barbastelle (*Synotus barbastellus*) of the southern parts of England, are solitary in their habits, generally retiring alone for their day's rest; others are more sociable, reposing in larger or smaller parties in their dormitories, whether natural or artificial, and sometimes, like the Fruit Bats, collecting in immense numbers.

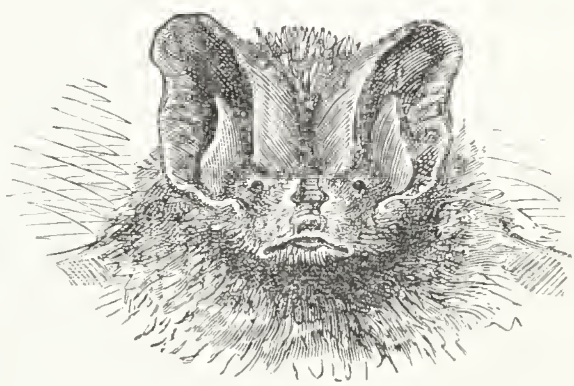

FIG. 3.—HEAD OF BARBASTELLE.

Our common Bats, like the Fruit Bats, sleep in what we should consider an exceedingly uncomfortable position, namely, with their heads downwards, but they cling by the claws of *both* hind feet to the small irregularities of the stone or wood forming the walls and other parts of the structure of their retreat. They frequent the same places year after year, so that, where they are numerous, the ground is often completely covered and discoloured with their excrements, which in some cases accumulate in course of time to such an amount as to have given rise to the

notion of carrying it away to be used as guano. The little blood-sucking Vampire Bats already mentioned take up their abode in caverns, and, according to Dr. Hensel, who observed their habits, they discharge their excrements, which are black and pasty, near the entrance of the cave just before starting on their evening flight, and this substance by degrees forms quite a thick layer (one foot or more) on the floor of the cavern. The Doctor says that a large dog which had paid a visit of curiosity to one of these caves came out again looking as if he had got long black boots on.

In the warmer regions of the earth's surface, where their supply of food is constant, the activity of the Bats is not known to have any intermission, but in cold and temperate countries they pass the winter season in a state of torpidity. The period of this hibernation, as it is called, varies somewhat in the different species, but few of them are to be seen flying about, except when the weather is decidedly mild. The commonest of all our British species, the Pipistrelle (*Scotophilus pipistrellus*), has a shorter winter sleep than any of its companions; it usually makes its appearance on the wing by the middle of March, and continues active until quite late in the year; in fact Mr. Gould has recorded the fact of his having shot a specimen of it on a warm sunny day just before Christmas. For the purpose of hibernation the Bats retire to their usual resting-places, but frequently, instead of suspending themselves by their hind feet, as when sleeping, pack themselves away in small parties in holes and crevices, an arrangement which probably furnishes a better protection against the inclemency of the season.

It is probably in the dormitory that the birth of the young Bats takes place—at least, so far as we know, the process is effected in a manner which must preclude active exertions on the part of the mother for some little time. The best account of the operation with which we are acquainted is that given fifty years ago by Mr. George Daniell, in a paper read before the Zoological Society, in which he described the habits of some Noctules kept by him in captivity. Four out of five died, and the survivor, a female, was observed on the 23rd June to become very restless, and to continue so for about an hour, although still suspended by the hind limbs in the attitude of repose. "Suddenly," to use Mr. Daniell's words, "she reversed her position, and attached herself by her anterior limbs to a cross wire of the cage, stretching her hind limbs to their utmost extent, curving the tail upwards, and expanding the interfemoral membrane, so as to form a perfect nest-like cavity for the reception of the young . . . which was born on its back, perfectly destitute of hair, and blind. The mother then cleaned it, turning it over in its nest; and afterwards, resuming her usual position, placed the young in the membrane of her wing. She next cleaned herself, and wrapped up the young one so closely as to prevent any observation of the process of suckling. At the time of birth the young was larger than a new-born mouse, and its hind legs and claws were remarkably strong and serviceable, enabling it not only to cling to its dam, but also to the deal sides of the cage. On the 24th the animal took her food in the morning, and appeared very careful of her young, shifting it from side to side to suckle

it, and folding it in the membranes of the tail and wings." Unfortunately, these interesting observations were cut short by the death of the mother, and the young animal, which was with some difficulty removed from the nipple, survived only eight days, during which it was fed with milk from a sponge, and made but little progress, its eyes being still unopened and its body almost hairless.

There can be no doubt that this process, varied in minor points in accordance with differences of structure, reveals to us what takes place in Bats generally in immediate connection with the birth of the young. From all the observations that have been made it appears certain that the female Bats produce only a single young one at a birth; that this is at first blind, naked, and helpless; and that the female nurses it carefully—a process which must be greatly facilitated by the power of clinging to its parent possessed by the young Bat from the first moment of its appearance in the world. The two nipples possessed by the female are situated upon the breast, sometimes quite at the sides under the arm-pits, a position which renders it particularly easy for the careful mother to tend her offspring, while she is also enabled to carry it about with her in her evening flights, the young creature clinging firmly to its mother's fur, and being quite out of the way of the movements of the wings. This part of the business, of course, could not be exemplified in Mr. Daniell's case, as the female was imprisoned in a cage, but it is a well-known fact in the natural history of these creatures that the mother does carry her young about with her so long as it continues helpless. Apparently, indeed,

even after the young animal becomes capable of flying about, its mother still retains some interest in its well-being—at least, if we may apply generally a case recorded by Dr. Allen in his account of the Bats of North America. It relates to a small species, the Red Bat (*Atalapha novæboracensis*), very common throughout the United States, a young individual of which having been captured by a lad, "three hours afterwards, in the evening, as he was conveying it to the museum in his hand, while passing near the place where it was caught, the mother made her appearance, and followed the boy for two squares; flying around him, and finally alighted on his breast, such was her anxiety to save her offspring. Both were brought to the museum, the young one firmly adhering to its mother's teat. This faithful creature lived two days in the museum, and then died of injuries received from her captor. The young one being but half grown, was still too young to take care of itself, and died shortly after."

This little anecdote seems to set the moral character of the Bat in a very favourable light, at any rate as regards the family affections, and there is no doubt that the females of all the species of the group show considerable fondness for their young. In other respects, perhaps, they do not all shine quite so brilliantly, for, as we have seen, the Fruit Bats squabble very selfishly for the most convenient sleeping places, as indeed do the other gregarious species of the order, and some of the former quarrel and fight over their food. As regards amiability of character, however, there is probably considerable difference between different kinds of Bats; at any rate, in confinement, they

show much diversity of temper, some of them being sullen, refusing food, and biting vigorously at their captors or the bars of their prison, while others are easily tamed and soon become familiar. Two of our commonest species, the Pipistrelle (*Scotophilus pipistrellus*), and the Long-eared Bat (*Plecotus auritus*), are among the latter. The Pipistrelle, which appears to be abundant throughout Britain, and indeed in most of the northern temperate regions of the eastern hemisphere, is a small reddish-brown species, measuring little more than one inch and a half in length without the tail, but with a spread of wing of more than eight inches. Its regular food consists chiefly of gnats, midges, and other small flies, in pursuit of which it often frequents the vicinity of water, but it has a curious predilection for raw meat, and in search of this it often makes its way into pantries, where the little thief will be found clinging to a joint of meat, and feeding upon it with avidity. This fondness for meat makes the Pipistrelle very easy to keep in confinement, as it diminishes the necessity of finding it insect food, and the little creature will in time become so tame as to take pieces of meat from its owner's fingers. It is an active and lively little creature, flying, running, and climbing about with great ease; in the latter operation, according to Professor Bell, it makes use of the extreme tip of the tail as if it was a finger.

The Long-eared Bat, so called from the great size of its ears, which are nearly as long as the whole animal exclusive of the tail, has perhaps a wider distribution than the Pipistrelle, but is hardly so abundant in Britain.

Its head and body measure nearly two inches long, while its wings spread to about ten inches. This Bat generally sleeps during the day under the roofs of houses and in church towers, and when sleeping its long ears are carefully stowed away under the folded wings, but the earlet or inner lobe of the ear still projects, so that the creature appears to have a pair of short-pointed ears. The Long-eared Bat flies very late in the evening, and indeed seems to continue its activity throughout the night; its food appears to consist to a great extent of the smaller moths, although other insects are by no means disdained. This species also soon becomes very tame and familiar; it will fly about the room, play with its fellows, and come fearlessly to take its food from the hand. Professor Bell gives an interesting account of one kept by Mr. James Sowerby, which, "when at liberty in the parlour, would fly to the hand of any of the young people who held up a fly towards it, and, pitching on the hand, take the fly without hesitation. If the insect was held between the lips, the Bat would then settle on its young patron's cheek, and take the fly with great gentleness from the mouth; and so far was this familiarity carried, that, when either of the young people made a humming noise with the mouth, in imitation of an insect, the Bat would search about the lips for the promised dainty." This habit of taking its food when off the wing, would seem to be natural to the Long-eared Bat under certain circumstances, as Mr. Tomes records his having seen one feeding in this manner upon the myriads of small moths which swarmed about a spindle-tree in bloom.

It is unnecessary to say that the creatures which display all this activity and intelligence are well endowed with at least all the senses possessed by the other animals of their class. The organs of smell and hearing are well developed, and in many cases associated with external membranous expansions of great size, as seen in the ears of the Long-eared Bat; and the eyes, though generally of small size except in the Fruit Bats, are bright and efficient, serving the creatures in good stead in the rapid pursuit of their insect-prey, which must be directed principally by sight. The common expression "as blind as a Bat" must be taken to apply to Bats accidentally driven from their retreats in the day-time, when it must be confessed that they fly about in a dazed manner, but at night and in their dark retreats they show no such imbecility of purpose, but find their way with astonishing precision and certainty. In fact, instead of being blind, the Bats must be especially-sharp-sighted, if all their evolutions be guided by the sense of sight, for in many cases they habitually resort to the inmost recesses of caverns and other places where, so far as our judgment goes, no light can possibly penetrate. Hence it was long since suspected that some other sense than that of sight must come to their aid when they plunge into such outer darkness as prevails in some places through which they fly with the greatest freedom, and more than a century ago numerous experiments were made by a distinguished Italian naturalist, the Abbé Spallanzani, in order to discover, if possible, what might be the secret of these curious phenomena.

He set free, in a long passage which was bent at a right angle about the middle of its length, a blinded Bat,

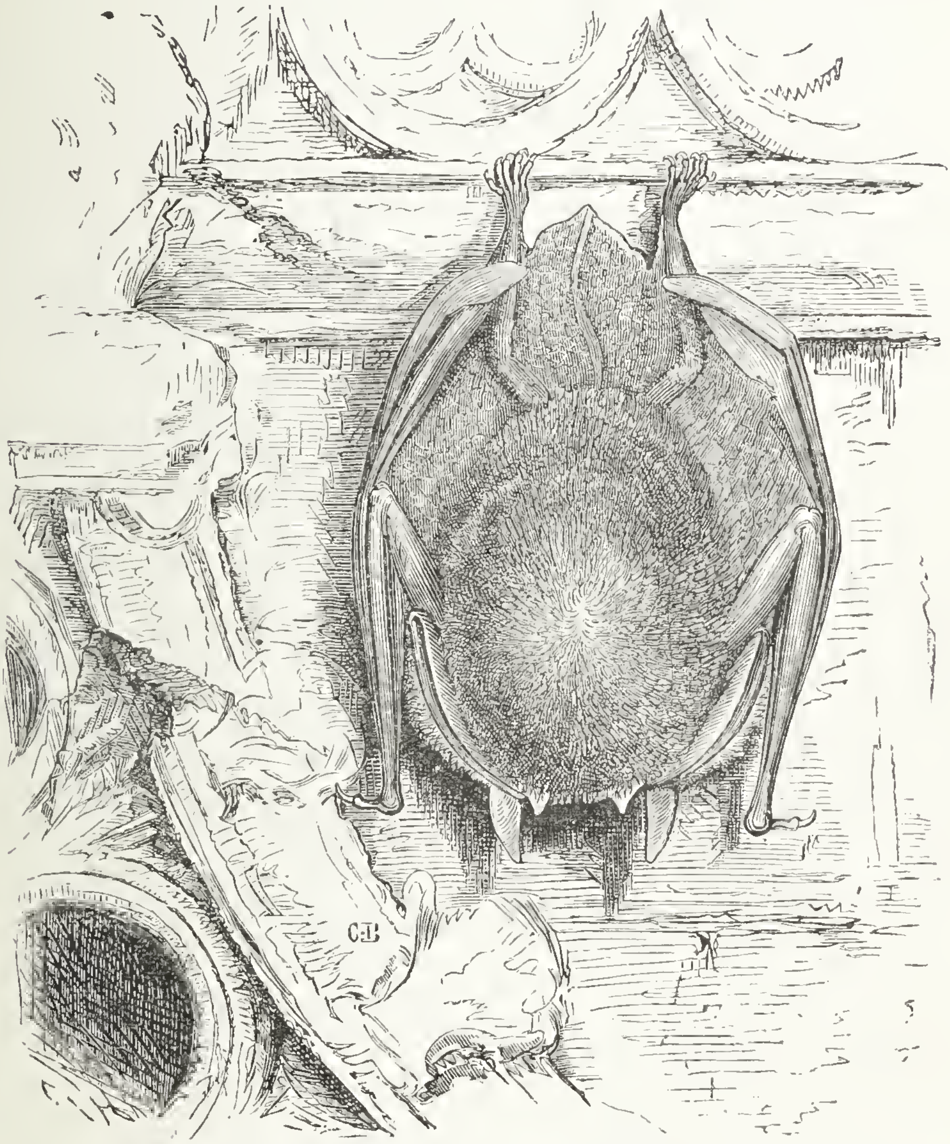

FIG. 4.—LONG-EARED BAT, SLEEPING.

which flew through the whole of this passage, turning the corner correctly, without anywhere touching the walls; while flying, too, it in some mysterious manner detected a hole in the roof at a distance of eighteen inches, and

proceeded at once to ensconce itself in this shelter. In another experiment the Abbé took two Bats, one blinded, the other not, and placed them in a space shut off from a garden and roofed in with nets, and with sixteen strings suspended from the top in different parts. Both Bats flew about briskly and avoided the hanging strings equally well, until at length the *blinded* Bat discovered that the meshes of the net were large enough for him to get through, when he at once made his escape, and after flying about for a short time, went off directly to the only roof in the vicinity, under which he disappeared. In short, from these experiments it became perfectly clear that under these circumstances the sense of sight was not of primary importance in guiding the course of the Bat. Similar trials with the organs of smell and hearing showed that they had nothing to do with it, and the only other sense that could be appealed to was the general sense of touch. Baron Cuvier, the great French comparative anatomist, was the first to suggest, from the consideration of the results obtained by the Abbé Spallanzani and others, especially by M. de Jurine, of Geneva, that the peculiar phenomena in question might be accounted for by the existence, especially in the great membranous expansions of the wings, of a most delicate sensibility, and subsequent investigations of the structure of those organs has tended to confirm this view, so that it is now the one generally accepted. It is found that these great membranes are traversed in all parts by numerous nerves, the delicate terminations of which form little loops, exactly resembling those which occur in our skin in those parts where the sense of touch is most highly developed;

and this resemblance is heightened by the fact that the membrane is covered with rows of little points. Even the organs of circulation in the wings are so constructed as to render it almost certain that those organs have a quite exceptional sensibility. Their ramifications are very numerous, and the veins as well as the arteries have contractile walls, rendering the circulation of the blood exceedingly active, the conditions, as Professor St. George Mivart remarks, being almost those of a state of inflammation.

If these membranous expansions have the functions just ascribed to them, we can easily understand that the larger they are the better, and this will explain why the Bats generally exhibit so great a tendency to run out into naked membranes. Thus although the ears, as organs of hearing, have probably nothing to do with guiding the Bat when flying in dark places, we find that in a great number of species the external ears are exceedingly large and delicately membranous, of which indeed we have an example in the British Long-eared Bat already referred to. In like manner, while the nose, as a nose, may also be left out of consideration, the development of membranous appendages of the part of the face in which the nostrils open is one of the most curious peculiarities of a vast number of Bats, in many of which these singular nose-leaves almost rival the ears in size, while their structure often renders them most grotesque. We have two Bats thus adorned in Britain, namely, the Greater and the Lesser Horse-shoe Bats (*Rhinolophus ferrum-equinum* and *R. hipposideros*), but most of the leaf-nosed species are in-

habitants of warmer regions, and it is there that they run out into the most remarkable eccentricities of structure. In Blainville's Bat (*Mormops Blainvillii*), a small species

FIG. 5.—HEAD OF BLAINVILLE'S BAT.

inhabiting South America and the West Indies, these expansions of the skin of the face seem to have reached the utmost possible grotesqueness (see figure), but the membranous leaves are larger and the ears much more developed in many species allied to our own Horse-shoe

Bats, especially such as the Megaderms. We can hardly imagine that these great membranous expansions of the outer ears and the region of the nose can have any other purpose than that of enlarging the surface of highly sensitive skin specially adapted for the perception of external impressions, and it is a remarkable fact, strictly in accordance with this view, that, so far as we know, the Bats so endowed are more decidedly nocturnal in their habits and frequent darker retreats than their less gifted fellows. Thus our Long-eared Bat, as already stated, continues active on the wing throughout the whole night, and the Horse-shoe Bats are distinguished as specially affecting dark caves.

FLAME.

By Professor F. R. Eaton Lowe.

A brilliant flame is the first object to fix the gaze of the young infant; and in manhood we still continue to feel a strange fascination under the influence of the same phenomenon. Even phosphorescence, unaccompanied as it is by flame, has an irresistible charm for us; while the vivid combustion of inflammable matter embodies a power and impetuosity which rivet the attention of the most stolid observer. We smile at the stupidity of the moth that singes its wings in the candle-flame; but there is within us a similar mysterious impulse that would impel us into the burning mass but for the consciousness of resulting injury, derived solely, as metaphysicians tell us, from knowledge gained by experience. Who is not struck with the splendour of a brilliantly-lighted hall or theatre? Indeed, the beauty and lustre imparted to large rooms by judicious lighting have no small share in the production of the vivacity felt by the audience generally. Turning to combustion on a large scale, with flames raging in uncontrollable fury, and material undergoing rapid destruction, there is probably no phenomenon in Nature except, perhaps, the electric discharge, that impresses us with a stronger feeling of awe. A conflagration, from a bonfire to a building in flames, from a chimney on fire to a blast furnace belching forth its

fiery tongues high into the air, is a fit emblem of ungovernable fury and relentless destruction. But it is more to our present purpose to regard flame as an instrument for good rather than evil. Most of the comforts and luxuries and even necessities of modern civilised life are due directly or indirectly to its agency; indeed, it would be difficult to name an art or manufacture which does not owe to flame its very birth. At home and abroad, in the house, the street, and the mart, we are surrounded by a multitude of substances which have been produced by the application of heat in one form or another. The spirit-lamp, the Bunsen burner, and the gas furnace, are the Alpha and Omega of the chemist's laboratory—the chief auxiliaries by whose magic power the multifarious compounds now become objects of commercial enterprise and sources of enormous wealth to the country, were originally prepared on a small scale. As a single example out of a thousand, take the manufacture of carbonate of soda from sea-salt, more than 200,000 tons of which, of the value of two millions sterling, are annually made in the alkali works of Great Britain. The salt is first converted into sulphate of soda by the action of sulphuric acid; the sulphate of soda is then converted into carbonate of soda by being heated with chalk and carbon. This important substance was formerly manufactured from barilla; and the interesting chemical process now employed on so gigantic a scale was the result of an experiment with substances heated in an evaporating dish by means of a spirit-lamp. Armed with his Bunsen burner the young chemist can produce a multitude of results not recorded in his books;

and the present rapid growth of applied science affords him every encouragement to persevere in researches which may result in discoveries of public utility.

All life, vegetable and animal, on the surface of the globe, is sustained by heat emanating from flames existing in the sun's photosphere or luminous envelope. These "red flames," as they are termed, are visible only during a total eclipse of the sun, and are of inconceivable magnitude, shooting with tumultuous fury to a distance of about 30,000 miles from its surface. Of the nature of these gigantic flames we shall have more to say anon; we prefer to begin our investigations at home, and lighting the humble and antiquated tallow candle, study the chemical reactions concerned in its combustion. Here we must say a word upon combustion generally. All the ordinary sources of illumination, as tallow, wax, oil, and coal-gas, are kept in a state of ignition by the oxygen of the air. If we place our lighted candle at the bottom of a wide-necked bottle, it will soon be extinguished from the want of its powerful supporter.

The flame of an ordinary lantern or lamp, where a chimney is employed, would not burn more than a few minutes if holes were not provided at the base for the ingress of air. But for the occasional application of the poker, the combustion of a common fire would be maintained with difficulty, or prematurely put an end to, for the oxygen of the air must find free access to the interior of the burning mass, or the chemical decompositions we are about to describe cannot take place. On the same principle the best way of extinguishing fire is to smother

it; that is, to cover it closely with something that will effectually cut off the source of its existence. If the clothes of some unfortunate friend should happen to catch fire, the best course to follow is to throw him down and envelope him in a rug, blanket, or anything of a similar kind within reach, when the flames will be immediately extinguished. To run about in search of water or assistance in these cases is simply to give time to the flames to reach a vital part of the body. But to return to our tallow candle, which is burning as brightly as can reasonably be expected from a consideration of the very small sum paid for it. If any prejudice against this humble luminary should exist in the mind of the reader, a glossy wax, paraffin, or composite candle will do just as well. With the flame before us two questions arise with respect to it. Firstly, What is it that burns,—the wick, the tallow, or both? Secondly, What is the composition of the tallow? The existence of the flame depends entirely upon the combustion of the tallow, the wick being simply a vehicle for its ascent in the melted state. The closely twisted fibres of the wick constitute a number of capillary tubes; hence the liquid tallow is said to rise by capillary attraction (Latin, *capillus*, a hair).

The phenomenon in this case, however, is simply one of suction; for the ignition of the wick at starting causes the ascent of the air in the fine hair-like tubes, and the melted matter immediately rises to fill up the vacuum, and undergoes decomposition at the summit. Without the wick we should have a furious conflagration instead of the slow combustion of a continuous stream of inflammable liquid.

The wick, consisting of cellulose or woody fibre, is principally carbon or charcoal, and consequently chars or becomes blackened during combustion.

It is quite possible to construct a lamp without the aid of any wick at all. We once saw sold in the streets of London an ingenious device for a feeble night-light at an almost nominal cost. It consisted simply of a wine-glass filled with oil, upon which was floated by means of a piece of cork a small tin tube with a very narrow bore. On the application of a light to the tube, the oil rose by suction and became ignited. The whole cost of the apparatus, including a supply of oil, was one penny.

Before we can understand all about the combustion of our candle, we must learn something of its composition. Like the majority of organic compounds tallow contains carbon, hydrogen, and oxygen—the two first being essential constituents of all highly combustible matter of vegetable or animal origin, as wood, cotton, oil, wax, coal, turpentine, resin, and camphor. The difference in the composition of tallow and wax in 100 parts is given in the following table. A stearine or composite candle differs but slightly in composition from one of wax.

	Tallow.	Wax.
Carbon	77	80
Hydrogen	12	13½
Oxygen	11	6½
	100	100

During combustion these elements enter into new combinations with each other, and with the oxygen of the air,

giving rise to a variety of inflammable gases, the nature of which we must now investigate.

Looking attentively at our candle-flame, we shall notice that it comprises three portions or zones, a dark zone in the centre, immediately surrounding the wick (*a*), Fig. 1; secondly, a luminous zone (*b*), from which its illuminating power proceeds; lastly, a dimly perceptible external zone (*c*) called the "mantle." In each of these areas special chemical reactions are taking place. The central zone is the *area of no combustion*, because the gases evolved from the tallow do not meet with sufficient oxygen for their ignition. This fact can be proved by a very simple experiment. Insert a very narrow glass tube, or the stem of a tobacco pipe into the dark zone, and the unburnt gases will be drawn-off, and may be ignited at the other end.

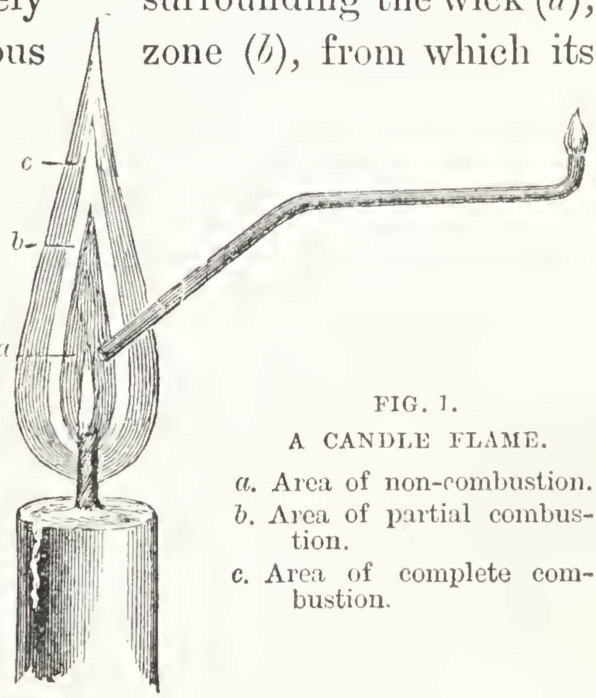

FIG. 1.
A CANDLE FLAME.
a. Area of non-combustion.
b. Area of partial combustion.
c. Area of complete combustion.

Another proof that there is no actual flame in this area is furnished by the fact, that, if a match or grain of gunpowder is placed in its centre, it will not be immediately ignited, but remain unconsumed till sufficient heat has been absorbed from the surrounding zone. The luminous zone is called the *area* of *partial* or *incomplete combustion*; because here, the gases meeting with an inadequate supply of oxygen, are only partially consumed, only part of the

carbon is converted into carbonic acid; and the remainder floats about in a white-hot or incandescent state, producing the luminosity, without which the light would be valueless. The external zone or mantle is the *area* of *complete combustion*, because here, the gases, meeting with the requisite amount of oxygen to oxidize the carbon and unite with the hydrogen, are completely burnt; and as there is no solid carbon in this part of the flame, its light is very feeble.

Gases Burning in the Candle Flame.—We have now to determine what are the gases given off by the melted tallow or wax.

We have already stated that the elements of the combustible material enter into new combinations with each other and the oxygen of the air under the influence of heat. If we first draw off the gases contained in the area of no combustion by the method just described, we shall be able to ascertain their nature, and then we can adopt a similar expedient with the other zones.

The gaseous products found in the candle flame are carbonic acid, carbonic oxide, olefiant gas, and other hydrocarbons, including marsh gas, hydrogen, nitrogen, and aqueous vapour. It will be necessary to say a few words upon each of these bodies if the reader wishes thoroughly to understand the condition of things in this and other flames, for the combustion of coal-gas, oil, wood, and similar substances, is attended by similar phenomena, and the products of combustion are almost identical, though differing considerably in relative proportion. One of the most important of these products is *carbonic acid*, or, as chemists prefer to call it, carbon dioxide, because it contains

two atoms of oxygen united with one of carbon. It is thus distinguished from carbonic oxide, or carbon monoxide, which has only one atom of oxygen to one of carbon. These bodies are conveniently written $C\ O_2$ and $C\ O$ respectively. As carbonic acid will not burn, it is evolved together with watery vapour, and enters the surrounding atmosphere. In these days of scientific progress every schoolboy is taught something of the properties of carbonic acid. He knows that it is a heavy gas, and, though invisible, can be poured out like water from one vessel into another. He knows, too, that it is one of the cast-off products of respiration, and, consequently, poisonous and irrespirable.

Notwithstanding this, we often take great precautions to prevent its escape. Scared by the ghosts of rheumatism and neuralgia, some people in winter close the doors of their apartments and stop up every crevice by which fresh air can enter or foul air escape.

By means of a sandbag at the window, another at the door, and a piece of list carefully tacked along its edge, the whole arrangement being supplemented by a screen, the products of combustion and exhalation are kept circulating in the room and breathed over and over again by those within, at the cost of morning headache, languor, and depression, with a long train of other evils following in the wake. From the fire, from the lights, and from the lungs of the inmates, the poisonous gas is evolved, and must be removed by efficient ventilation. We are here struck by the remarkable analogy between the process of combustion and the function of respiration.

The latter is, in fact, a species of combustion without

flame. The carbon of the impure venous blood unites with the oxygen of the air to form carbonic acid gas, while the hydrogen unites with another portion of oxygen to form water. Both products are expelled at each exhalation, and the chemical action going on within the body raises its temperature to nearly 100°. To prove the presence of carbonic acid in our candle flame, we have only to siphon it off by a bent tube, as in Fig. 1, and pass it into lime water, which will become milky owing to the formation of carbonate of lime or chalk. In the same way we can show the presence of carbonic acid in the breath on simply blowing down a tube into lime water (made by shaking up powdered quicklime with *distilled* water) an immediate precipitate of carbonate of lime will be produced. We all know that aqueous vapour is exhaled from the lungs.

To show its production in our flame invert over it a dry tumbler. In a few seconds the interior will be covered with moisture owing to the condensation of the vapour. *Carbonic oxide* differs from carbonic acid in being combustible, and is, therefore, consumed in the flame. In burning, however, it takes an atom of oxygen from the air, and produces CO_2 or carbonic acid. It is this gas which burns with a blue flame at the top of our coal fires. The carbonic acid formed at the bottom of the grate, loses half its oxygen in passing upwards through the red-hot coals and again reverts to its original condition on combustion. There is consequently no destruction in nature.

What appears to be lost simply assumes another form, and passes into the atmosphere to play another and more important part. What is rejected by man and animals as

a poison is the very pabulum of plants, and the chief source of their substance.

Olefiant Gas is an important ingredient in our candle or gas flame, as it is the chief illuminating agent. It is sometimes called heavy carburetted hydrogen, and its formula is written $C_2 H_4$. Its name—olefiant (oil-making), was given to it on account of the oily liquid which it forms when combined with chlorine.

These compounds of carbon and hydrogen are called *hydrocarbons*, and constitute a very large class. Some of them are solid, as paraffin and naphthalin; others liquid, as turpentine, petroleum, benzol and camphine; and others gaseous, as marsh gas and olefiant gas. As may be expected from their composition, these hydrocarbons are highly inflammable, and burn with a more or less smoky flame in proportion to the amount of carbon they contain. Those which contain the largest number of atoms of carbon capable of uniting with hydrogen, such as paraffin, are called *saturated hydrocarbons*. Paraffin candles are made of a mixture of paraffin and wax, and give a very fair light, because several other "olefines" besides olefiant gas are present in the flame. The illuminating power depends upon the separation of carbon in the solid form, and its incandescence in the zone of incomplete combustion. Olefiant gas, like carbonic oxide, produces carbonic acid by its combustion. We shall describe an easy method of preparing it in the pure form when we come to speak of flames of special interest.

Marsh Gas.—This gas which burns in coal-gas flame as well as in our candle flame is so called because it occurs in nature over stagnant pools and marshes, having been

formed by the decomposition of dead leaves and other vegetable matter. It may be collected from these pools by stirring up the mud at the bottom and receiving the bubbles of gas in an inverted bottle filled with water. (Fig. 2).

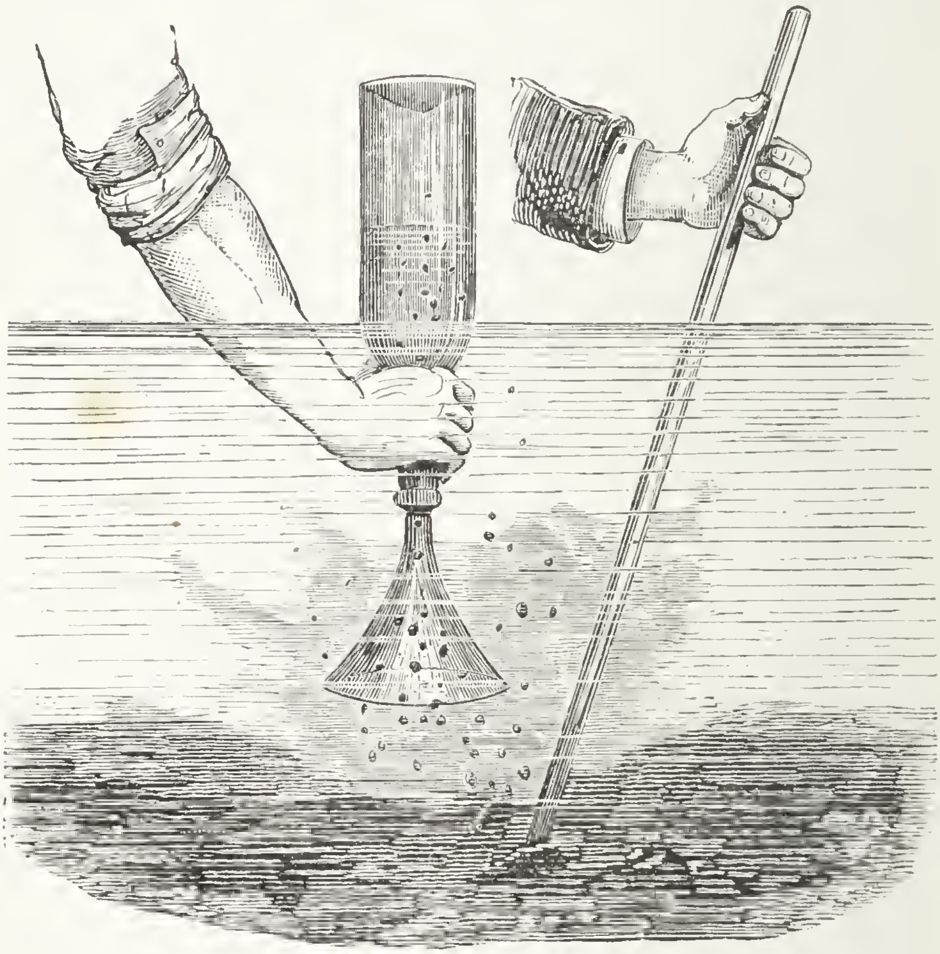

FIG. 2.—COLLECTING GAS FROM A STAGNANT POOL.

Marsh gas or light carburetted hydrogen, $C H_4$, constitutes the "fire-damp" of coal mines, issuing sometimes in enormous quantities in "blowers" from the coal seams. This gas, like the other hydrocarbons, forms carbonic acid and water by its combustion with oxygen.

Hydrogen.—This is the lightest gas in nature, its

weight being one-fifteenth that of common air, on which account it is used for filling small balloons. It forms an explosive mixture with air; and as it is found free in coal-gas it becomes an element of danger wherever there is an escape from the pipes into a closed apartment.

Coal-gas Flame.—The bodies whose properties we have thus briefly summed up are found in coal-gas, the flame of which does not differ much in its chemical reactions from that of a candle. The gas, however, differs much in composition and illuminating power in different towns, the proportion of its constituents varying with the quality of the coal employed, and the temperature to which the retorts are raised. Sometimes the purification of the gas is incomplete; some of the products of the distillation, such as carbonic acid, sulphuretted hydrogen, and di-sulphide of carbon, are not only valueless as illuminating agents, but communicate to the gas a disagreeable odour, and must therefore be removed before the gas passes into the gasometer.

These sulphides produce by their combustion sulphurous acid—a gas of a pungent suffocating character; and if present at all in coal-gas may be detected by the application of lead paper, or paper impregnated by a salt of lead. The paper will become blackened by the formation of lead sulphide. The following table represents the composition of coal-gas of good quality:—

Marsh Gas	41·88
Hydrogen	41·71
Carbonic Oxide...	4·98
Olefines	8·72
Nitrogen	2·71
	100

In some samples we have found no nitrogen, the whole of that element having united with hydrogen to form ammonia, one of the secondary products of the gas manufacture. The composition of different parts of a coal-gas flame has been examined by Professor Landolt, who gives us the following results :—

Height from Burner in inches . . .	0·	0·39	0·79	1·18	1·58	1·97
Total volume of Air and Gas before burning . . .	127·08	145·43	272·76	327·73	435·3	481·66
Total volume of Gas after burning . .	111·41	120·09	245·96	311·37	422·59	461·23
Hydrogen.	22·66	14·95	5·49	15·54	14·5	11·95
Marsh gas	33·77	30·2	28·34	21·55	11·92	3·64
Carbonic oxide . . .	7·34	14·07	14·05	14·58	22·24	25·14
Olefines	7·29	7·49	7·87	7·94	7·05	5·45
Oxygen	0·66	0·78	0·47	..	...	...
Nitrogen	29·41	38·66	140·7	184·23	270·45	307·1
Carbonic acid . . .	1·94	2·34	10·11	14·98	23·76	32·34
Water	8·34	11·6	38·85	52·58	72·67	75·61

In the column marked "0· *inches*" we have the proportion of gases occurring immediately in contact with the wick, and the distances increase up to 1·97 in., which may be taken as two inches. We find the quantity of hydrogen decreasing up to 0·79 inches, when there is a sudden increase, owing, probably, to its liberation from the watery vapour by the action of the highly-heated carbon at this point. It will be noticed that the quantity of water rapidly increases towards the summit of the flame,

where it passes out into the air. A similar increase is observable in the case of the nitrogen, derived from the decomposition of the air, the oxygen of which combines with the carbon and hydrogen to form carbonic oxide, carbonic acid, and water. The nitrogen is an inert body, and does not combine with any of the gaseous matters in the flame; it therefore escapes unchanged. It will be seen that there is no uncombined oxygen above 0·79 in. The increase in carbonic oxide is due to the action of the highly-heated carbon on the carbonic acid, CO_2, which parts with one atom of oxygen and becomes CO.

Cause of Luminosity in Flame.—We have already stated that the presence of solid carbon in a white-hot state is the cause of luminosity in flame generally. Davy proved this by bringing into contact with the flame a cold substance, when a deposition of soot or carbon was the result. The chemist is acquainted with brilliant flames in which there is no solid matter; but as a general rule the presence of such matter considerably increases the illuminating power. If we project air or oxygen into a flame we destroy its luminosity by dispersing the luminous matter over a wider area, and thereby facilitating the conversion of the carbon into non-luminous gases. We are all familiar with the spluttering blue flame sometimes produced when we first light the gas, in consequence of the admixture of air in the pipes. The reduction of temperature which takes place in this case has much to do with the phenomenon, for we shall presently show that the introduction of nitrogen, steam, or any gas exerting no chemical action on the flame, destroys its luminosity as

completely as oxygen. If the air or gas to be passed into the flame is first heated, the luminosity at once returns.

It is therefore obvious that the old theory supported by Davy and maintained by other chemists almost up to the present time, respecting the connection between oxygen and flame luminosity, requires modification. The effect appears to be quite as much due to the nitrogen, which, as a reference to the table just given will show, is given off in gradually increasing quantities, and assists in reducing the temperature. The effect produced by mixing air with coal-gas is well seen in the Bunsen burner, which has almost superseded the spirit-lamp, and is universally used in the laboratory for heating flasks, retorts, air baths, &c. It consists of an ordinary gas-burner surrounded by an iron cylinder. At the base of the cylinder there are holes for the admission of air, which rises with the gas to the summit, where the mixture is burnt. The flame is non-luminous, and is not only hotter than an ordinary flame, but has the advantage of not blackening the apparatus heated by it. If we stop up the holes at the base, which can be effected by simply turning the cylinder round, the unmixed gas alone rises, and the flame becomes luminous. That this flame is hollow like that of a candle can be shown by passing into its centre a match, which will not ignite at once, and also by bringing rapidly down upon it a piece of stout white blotting paper, which will exhibit on withdrawal a charred ring.

The effect of nitrogen or steam upon the non-luminous flame may be tried in the following way :—Stop up one

of the air-holes with a cork, and into the other fix a tube communicating with a gasholder containing nitrogen gas.

The passage of the air being cut off, the flame burns with a bright yellow light, but as soon as the nitrogen gas is allowed to mix with the coal gas, the flame becomes blue and non-luminous. Instead of nitrogen we can send into the burner a current of steam from a flask of boiling water when the same effect will be produced. Conversely we can render a non-luminous flame luminous by raising the temperature of the nitrogen before its introduction into the burner. This can readily be done by fitting a metal tube into the air-hole and connecting it with the delivery tube of the gas-holder. The tube being heated by a lamp placed below it, the temperature of the nitrogen is raised and the flame immediately becomes luminous. Dr. Frankland's recent investigations on the nature of flame have led him to the conclusion that the luminosity of flame is not due to solid carbon, but to a mixture of hydrocarbons capable of condensation like water from steam.

The increase of brilliancy imparted to flame by the presence of incandescent solid matter can be illustrated in various ways. The well-known experiment, so familiar to young chemists, of burning phosphorus in oxygen furnishes an excellent example. When the ignited phosphorus is passed into a jar of the gas by means of a deflagrating spoon, the whole vessel is filled with a most dazzling white light, owing to the dispersion of solid phosphoric acid, PO_3, produced by the union of the two elements.

When sulphur is burned in the same gas, the blue flame which is produced has not the same luminosity, because the product, sulphurous acid, S O, is not solid but gaseous. The combustion of magnesium affords another illustration of the same principle. The intense white light emitted is due to the presence of solid particles of incandescent magnesium oxide or magnesia when metallic zinc is melted in a crucible, a beautiful luminous flame is seen to play over its surface owing to the formation of solid oxide of zinc in woolly flakes; hence in this state it was formerly known as

"Philosopher's Wool."—The oxy-hydrogen flame is scarcely visible in daylight; but if allowed to impinge on a ball of lime to produce the "lime light," we get one of the most brilliant and luminous flames with which we are acquainted. Coal-gas is now usually employed instead of pure hydrogen to mix with the oxygen. In the production of this light the oxygen must be kept in a separate bag, and allowed to mix only with the coal-gas in the burner, which must be of peculiar construction, otherwise the flame might pass down the tube and give rise to a violent explosion.

A safe and easy method of showing the lime light is to fill with oxygen a bag to which a brass cap and long nozzle is fitted, and to force a stream of the gas through a hydrogen flame issuing from a glass tube attached to the bottle in which the hydrogen is prepared. The flame is allowed to impinge upon a cylinder of lime, and intense ignition follows. The cheapest, and perhaps the safest jet that can be used for the lime light is Tate's. It

consists of a cylinder of japanned tin plate, six inches high and two inches wide, closed by a cork at its upper end, and standing upon a heavy foot. The blow-pipe jet is connected with a tube filled with several pieces of wire-gauze to prevent the passage of the flame into the cylinder. The gas delivery tube brings the mixed gases from the reservoir into the cylinder which is filled with water to within an inch of the cork. The tube is closed at its lower end by a valve of silk. If from any imperfection in the gauze packing the flame should happen to pass into the space below the cork, the small quantity of gas enclosed therein will explode with no other result than the expulsion of the cork.

The gases pass into the burner from separate reservoirs through the tubes, and the supply is regulated by stopcocks. There is a movable stand for the support of the lime cylinder. By means of a screw the table upon which the burner and lime stand are fixed may be turned in any direction.

Dr. Frankland has pointed out certain other causes which affect the luminosity of a flame, as the degree of condensation suffered by the burning body and the relative weight of the products of combustion. Thus the flame of alcohol is but feebly luminous under ordinary circumstances, but becomes much brighter in condensed air. The same phenomenon is observable with the oxy-hydrogen flame under pressure. A candle burns with a less luminous flame at the top of a high mountain than it does in the plain below.

As the amount of oxygen in a given volume of air

increases with the density, these cases seem to involve a reversion of the law already laid down with respect to the cause of luminosity generally.

The effect, however, is due to the compression of the luminous material into a smaller compass. Similarly with regard to the products of combustion, the higher their density the brighter the light emitted. Thus hydrogen burns in oxygen with a flame of little luminosity, but its combustion in chlorine is more vivid. The product in the first case is water, H_2O, and in the latter, hydrochloric acid, HCl, the specific gravities of which are respectively 1000 and 1210. We have already referred to the effect produced upon flame by the presence of heavy olefines or hydrocarbons. This action has been taken advantage of in the construction of the new "hydrocarbon" lamps, in which coal-gas is saturated with the liquid hydrocarbon before its ignition. The gas on its way to the burner passes through a ball containing pieces of paraffin kept in a melted state by a small jet underneath. It thus becomes enriched with carbon, and gives a flame of great illuminating power. This lamp has been introduced into some of our places of amusement, and is certainly one of the most effective and convenient forms of illumination for large buildings at present in use. The gas companies, put upon their mettle by the triumphal march of the electric light, have recently turned their attention to the improvement of the burners, and have devised some very effective street lamps, well adapted for central positions. The burners are constructed on the principle of the Argand lamp and Berzelius spirit lamp, in both of which circular wicks are employed, so as to permit

the passage of air through the centre of the flame, thus securing a more perfect combustion. The burners consist of two or three concentric rings, producing the same number of hollow cylindrical flames, and being surmounted by a conical reflector, a powerful flood of light is diffused below.

The illuminating power of coal-gas is generally estimated in candles; the gas burning at the rate of five cubic feet per hour being compared with a sperm candle burning 120 grains per hour. Thus an ordinary coal-gas flame is equal to fourteen candles, but there is much variation in this respect, the cannel coal used in some parts of Lancashire giving a flame of thirty-four candle power. The light of some of the new concentric burners is said to be equal to that of 200 candles.

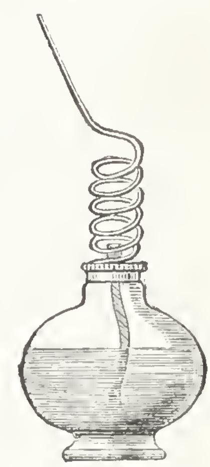

FIG. 3.
FLAME EXTINGUISHED BY SPIRAL WIRE.

Flame and Conduction.—If we withdraw heat from a flame by means of a good metallic conductor, combustion becomes imperfect, if not altogether suppressed. The heavy hydrocarbons become condensed, and solid carbon is rendered visible as a cloud of smoke. Thus, if a coil of cold copper wire (Fig. 3) is held over a small flame it is extinguished; and an iron spoon placed upon the apex will produce a stream of dense black smoke. A striking experiment in illustration of this can be performed with a Bunsen burner and a piece of fine wire-gauze having about 700 meshes to the square inch. The gas is turned on but not ignited, and the sheet of gauze held over it about an inch from the top (Fig. 4). The gas will pass through, and may be inflamed

on the upper surfaee, but no flame will be visible below, beeause too much heat is withdrawn by the metal. The gauze may be moved upwards to the extent of another ineh or two and the flame will be lifted with it, till the large admixture of air extinguishes it. On this principle Davy eonstrueted his famous safety-lamp, whieh has done sueh useful serviee to miners (Fig. 5). The lamp is surrounded with wire-gauze through whieh the fire-damp enters and is inflamed within; but heat being withdrawn by the metal, the mass of inflammable gas without cannot take fire, and thus the miner has time to make his eseape before the gauze beeomes red hot.

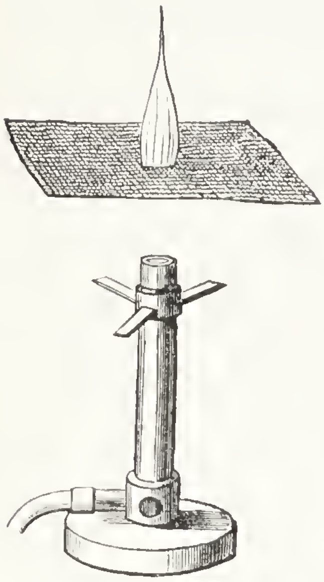

FIG. 4.—FLAME ABOVE THE GAUZE.

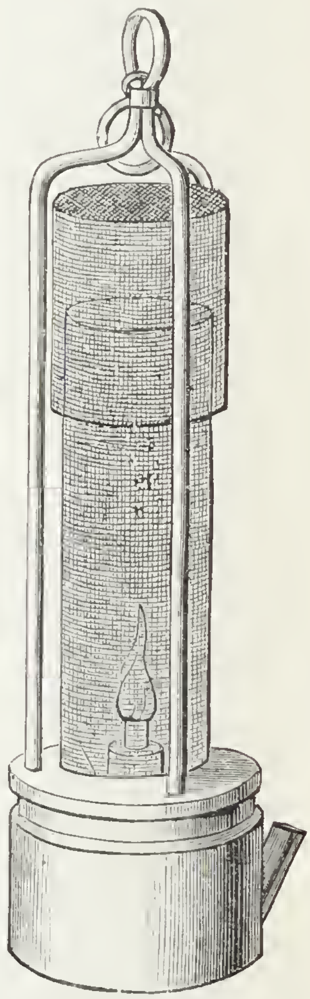

FIG. 5.—THE DAVY LAMP.

Modifications of Bunsen's Burner.—Sinee the invention of Bunsen's burner, numerous modifications have been employed for heating purposes, not only in the laboratory, but in the arts and manufactures. In the "gauze top" burner the cylinder is two inches in diameter, and eovered with a sheet of wire-gauze. The mixture of gas and air passing through the gauze is ignited and gives a large flame of

great power suitable for heating crucibles, large evaporating dishes, &c. In what are called *solid flame* burners, the diameter of the gauze is increased, so as to produce a flame six or eight inches across, and capable of boiling several pints of water in a few minutes. Furnaces for fusion, assaying, and metallurgical purposes, are formed of a combination of burners. They are placed in close contact, and the heat of the flame is augmented by the aid of a blowing machine worked by a treadle. Griffin's blast gas furnace made upon this principle, is capable of melting thirty-two ounces of copper or cast-iron in ten minutes.

In Hofmann's furnace for heating combustion tubes, there are as many as 170 Bunsen burners in two parallel rows, and placed so closely together as to give almost a continuous line of blue flame.

Olefiant Gas.—As olefiant gas and similarly constituted bodies are the chief illuminating constituents of coal-gas, it may not be out of place to give the reader a description of some experiments illustrating the nature of heavy carburetted hydrogen in a state of purity. Its preparation is very simple. Pour into a flask a mixture of two ounces of alcohol or methylated spirit and the same bulk of strong sulphuric acid. Close the flask with a cork through which is passed a narrow glass tube. A gentle heat is applied by means of a spirit lamp or Bunsen burner; and when the gas is given off, it may be ignited at the orifice of the glass tube. A large luminous flame upwards of a foot in length will be thus produced. It may be useful to compare this flame with that of ether under similar circumstances. A little common ether is to be placed in a

small flask fitted in the same way as in the previous experiment. On the application of a very gentle heat, vapour will be given off abundantly, and yield, on ignition, a flame nearly a yard in length. A jar of the gas may be collected at the pneumatic trough by using a retort or a flask fitted with a glass tube bent at an acute angle. The jar is to be turned mouth upwards, and the gas inflamed, when it will burn with a large, smoky flame, the size of which may be considerably increased by pouring in water from a jug or beaker, the effect of which is to drive the gas out of the jar. To show the presence of black charcoal in this gas, one volume of it is mixed with two volumes of chlorine in a tall jar, and inflamed. A dull lurid flame will pass slowly down the jar, while a dense volume of black smoke will be given off. The student should be careful to make this mixture at night, as it is liable to explode spontaneously in sunlight. Olefiant gas mixed with three times its volume of oxygen explodes violently when inflamed; and coal-gas mixed with ten times its volume of common air is similarly explosive; hence the necessity for caution when an escape of gas into an apartment is observed.

The Blowpipe Flame.—When the flame of a Bunsen burner is acted upon by a blowpipe, it divides itself into two portions, one within the other, called the reducing flame and oxidising flame respectively. In chemical action these flames are opposed to each other, one imparts oxygen to a metal subjected to its influence, while the other abstracts oxygen from an oxide, and reduces the metal. The inner flame is the reducing flame, because here there is excess of carbon, which unites with the oxygen

of an oxide exposed to it. The outer flame is the oxidising flame, because here the heated oxygen tends to unite with any metallic body exposed to it to form an oxide.

These reactions are of the greatest importance in chemical analysis. A fragment of the solid to be tested is placed upon charcoal and heated by the blowpipe; in a few seconds, if the substance is a metallic salt, little globules of metal will make their appearance, the nature of which can readily be determined.

Coloured Flames.—Certain vapourisable salts communicate colour to flame by being carried up with the heated gases, as in the process of sublimation. Thus salts of strontium communicate a red colour, salts of copper a green colour, sodium salts yellow, and potassium salts a violet tinge. These colourations are best shown by saturating alcohol or methylated spirit with the respective salts and setting it on fire. A striking experiment known as the "*Fire cloud*" is performed as follows:—Dissolve in a pint of methylated spirit five parts of chloride of strontium, and one part of nitrate of copper, or boracic acid. The mixture is to be projected with some force upon the ceiling of a room by the aid of a syringe or metallic fountain, in which the air can be condensed. The spirit being inflamed a brilliant cloud of variegated fire will be produced. The experiment is free from danger, as the combustion is too rapid to cause ignition of the wood-work. It should be noted that methylated spirit is not so well adapted for showing these coloured flames as pure alcohol, as it burns with a yellowish flame, in consequence of the smaller proportion of carbon in its composition.

The flame of pure spirit (ethyl alcohol) is pale blue, a tint which permits the red and green flames to show in stronger relief. An expeditious method of conducting the experiment is to ignite the spirit in a saucer or evaporating dish, and then to throw into the flame the various salts in fine powder.

The violet tint of potassium and the yellow of sodium are best shown by using the metals themselves. A fragment is simply to be dropped into water, which, in the case of sodium, must be hot.

Our space is now exhausted, but the field of research opened up by our subject is inexhaustible. Flame was the mighty Frankenstein to whom the old alchemists looked for aid in their visionary schemes of transmutation; but since the time of those assiduous but misguided philosophers, flame has worked greater wonders than ever entered into their wildest fancies. The diligent experimenter may be assured that much still remains undisclosed, and that by means of the Bunsen burner, blowpipe, and blast-gas furnace, discoveries have yet to be made which will, at the same time, startle and benefit the world. Our experiments, however, must not be simply tentative; they must be begun, continued, and ended in accordance with physical laws, which will never change, whatever may be the ultimate revolution in scientific theories. By heat the elements can be separated, and by the same agency they can be combined; the more perfect, therefore, our knowledge of chemical action and reaction, the more likely are our researches to terminate in satisfactory results.

BIRDS OF PASSAGE.

By Dr. Robert Brown, F.L.S., etc.

The least observant person who walks even a short distance beyond the range of bricks and mortar cannot fail to notice that in early spring a strange uneasy movement seems to pervade every living thing. Nature appears to have woke out of a long sleep, and now, after the torpidity of the winter, is resuming the active existence which was suspended in October. Hardy flowers are springing up in sunshiny spots, and the gay catkins of the willow and alder are braving the east winds even before the leaves have expanded. The buds are bursting visibly, and even audibly; the butterfly has left its chrysalis; and the cautious snail, which for months past has been hybernating in a snug hole in the wall, is preparing to taste the tender herbage beginning to sprout above the half-thawed soil. In evening, provided the day has been warm, and insect life sufficiently plentiful, the bats may be seen flitting round the old barn in which they have been passing the idle season, and a sharp eye may easily enough detect among the dead leaves the harvest mouse and other little mammals, which are for the first time venturing abroad in the hope of finding provender enough to reward their temerity. Even inanimate Nature is bestirring itself. The brooks are noisy with the melting snow of the still snow-capped hills, and the drip, drip, which, ac-

cording to the Roman poet, wears the stone not by force, but by often dripping, seems to supply an accompaniment to the general stir which is proceeding apace.

But what betokens the arrival of spring even more than the crawling of snails or the flutter of insects is the arrival of the migratory birds. That they are migratory is to most of us a matter of such familiar knowledge that we no more think of questioning it than we conceive it necessary to doubt the rotundity of the earth or the waning of the moon. We know that certain feathered friends are here during the summer, and it is equally certain that they are absent a few months later, only to appear with the first flowers and the pioneer bees. In March—and sometimes even earlier—the chiff-chaff, the pipits, and the wheatear, appear respectively in copse, on river bank, and open commons and deserted wastes. By the first week in April the whin-chat and the stone-chat are hopping about the last-named locality; then the hedgerows appear peopled as if in a night with willow warblers, while fruit trees attract the black-cap, the wood warbler, and the white-throats. The season must be a late one if the cuckoo is not heard by the middle of the same month, while the nightingale, which is so chary of extending her range beyond a certain northern line, drawn it would seem almost arbitrarily, is to be heard in lavish numbers in certain favoured spots. The red-tail is here from Egypt and Abyssinia, and, as they have nests to build and eggs to lay on the shores of the White Sea, the chances are that in a few days more the shivering citizen of Archangel may be rejoiced by the sight of the more enterprising

members of the flock. The water wagtails are twittering on the muddy shore of the water-course which so recently overflowed its banks, and by the end of April the turtle-dove is cooing in the fir-wood, as if rejoiced at once more seeing its native land after the prolonged visit to Nubia and the Upper Nile. The corncrake (p. 87), which seems, with its skulking habits and ungainly appearance, little fitted for the long flights it is compelled to make twice in the twelve months, suddenly proclaims its presence from amid the early corn; and if lucky, the ornithologist may catch a glimpse of the gay hoopoe and the golden oriole, which have an exotic aspect, and are indeed only occasional visitors to these northern climes. The fly-catchers are rarely here before the second week of May, but long before that period the familiar swallow has assured us—the proverb notwithstanding—that summer is here at last. The sand-martin is the earliest of its kindred to come and the soonest to leave; and the swift is so apt to linger on its way, now hawking around a Kaffir kraal in South Africa, anon halting a little while in circles about the Moorish towers of the Alhambra, from the windows of which, in happier days, the languid ladies of the harem used to angle for them with artificial flies, so the spring is well advanced before it appears on the English downs. All summer these little feathered folk revel in the joy of existence. The pair build their nest, rear their young, and disappear, until the observer who was intent six months before in watching their arrival may find a sadder but not less intellectual amusement in noting how one by one they vanish from the woods, the commons, the

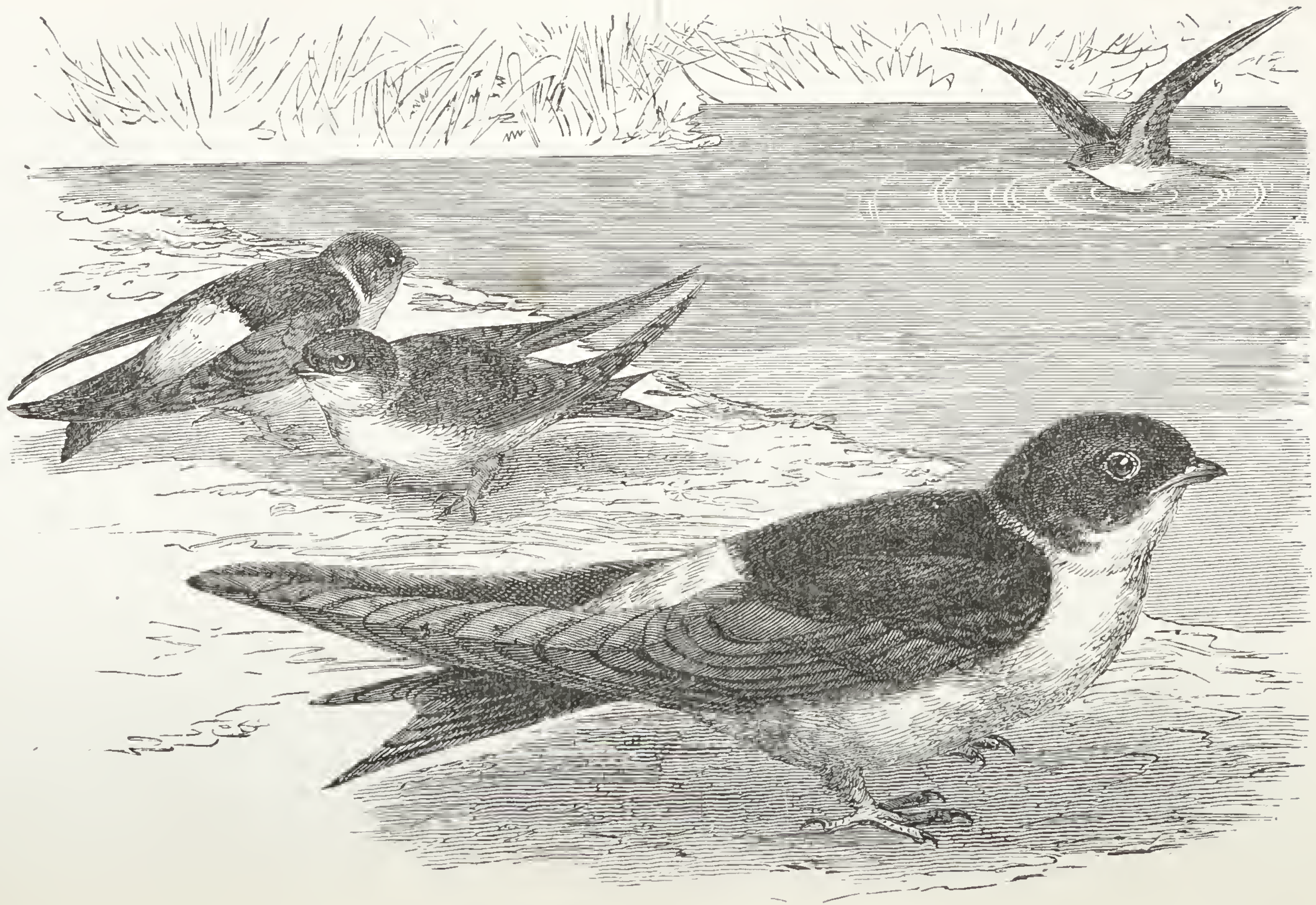

Fig. 1.—THE MARTIN (*Hirundo urbica*).

fields, the gardens, and the river sides, where they had to all appearance established themselves for good.

By October some of them have left. Almost before the falling leaves enable us to fully realise that autumn has arrived, the flycatchers, the warblers, and pipits, vanish from their accustomed haunts. Before the stubbles are bare the white-throat is on its way to Malta, or Corfu, or Asia Minor, and the chiff-chaff, which was braving the east winds of March, takes care to be ready for a flight to Sicily before the September gales have ruffled her dainty plumage. The nightingale, it is a matter of almost general knowledge, is curiously limited in its range over England. In summer it flies as far westward as the Spanish Peninsula and as far northward as Denmark, yet it is absent from Ireland, and its rumoured visits to Scotland are not very generally credited; while, according to Mr. Harting, the boundary line over which it rarely trespasses takes in Cornwall, West Devon, part of Somerset, Gloucester, Hereford, the whole of Wales, part of Shropshire, the whole of Cheshire, Westmoreland, Cumberland, Durham, and Northumberland, though it has been doubted whether its range is much north of the town of York. Its western boundary seems, therefore, formed by the valley of the Exe, the occasions on which it has overstepped this limit being extremely rare, and in many cases its supposed occurrence in certain spots and at certain dates rests entirely on the *ipse dixits* of people who affirm that they "heard its song." The "early nightingale" of the newspaper paragraph is usually a song thrush. The bird rarely, if ever, makes its appearance in

these islands before the fifteenth of April. What is more, it shuns Brittany and the Channel Islands, though so numerous are they in the valley of the Thames, that bird-catchers will sometimes secure a couple of hundred after a few nights' work. Yet, though so abundant that as soon as the first glimpse of spring is on us the Philomel is chanting his "harmonious love" in every grove from Twickenham to Blackheath, and delighting late loungers on river-side lawns with his sweet concert, after the middle of June it is only in exceptionally mild localities that a single note can be heard from the songster, which, according to Fletcher and an absurd bit of folk-lore, "singeth with 'her' breast against a thorn." At the first approach of autumn, Philomela is off with other blithesome feathered friends to the Mediterranean, and is rejoicing the sad hearts of the invalids who, like her, are trying to escape their native fogs in Tangier, Cairo, or Smyrna. The wheatear will before then have deserted the rabbit warren, and the whin-chats and stone-chats are no longer to be seen on the furzy common, where the linnet and the brambling have taken their places. Thrushes and meadow pipits, which had fled from the snows of their summer haunts by the Petchora and the North Cape, have usurped the strongholds of the whitethroats and yellow wagtails, and the home of the tuneful willow-wrens by the bosky hedge-rows and coverts are tenanted by noisy tits, reckless of the coming storms. Some few, indeed, seem as if uncertain whether to go or to remain. Pied wagtails and woodcocks may be found all through the winter, and other birds, like the song-thrush and the robin-redbreast, which are

faithful to England in sunshine and in storm from January to December, are in many Continental countries regular migrants. The wax-wing, the nut-cracker, and the Pallas sand-grouse, though not usually reaching our longitudes, are sometimes impelled to migrate by that longing for travel which seizes so many of their kindred. But the cuckoo, the nightingale, the swallow, the swift, and the martins, are pre-eminently our migratory birds. They are associated with spring and summer and autumn; and though the newspapers never fail to record the fact of a stray specimen having been shot in some remote quarter, one no more looks for a corncrake or a swift in February than for the sea-serpent or the sulphur shower when Parliament is fairly in session.

But marked though the migratory season is in England, we see less of it than do our Continental neighbours, especially those who inhabit countries on the line of the great spring and autumn flights to and from the north of Europe. Morning and evening, and, indeed, all day long, the Heligolander may watch from his red rock in the North Sea the wild ducks winging their way in long "badelynges," led by an elderly drake performing the part of a personal conductor, and quacking with joy at the sight of the river mouth which they had in memory ever since they left the Lapland lakes or the Siberian tûndra. Every night—unless the sky is clear and the moon enables the migrants to continue their flight without trepidation—there is a Babel-like clamour overhead, and the lighthouse lantern is surrounded by myriads of larks, snipes, and plover, which have beat against it on their dreary night

journey from the north, or by the mysterious-mannered knots returning from their philanderings in some nameless land around the Pole. In one night sometimes as many as 15,000 larks have been caught, and though the resident birds of Heligoland do not exceed a dozen species, it is, perhaps, no exaggeration to say that the visitors exceed those of the greatest country in Europe.* But on a smaller scale the same spectacle may be witnessed in almost any spot similarly situated. For example, the keeper of the lighthouse at Atlantic City describes the migratory birds as following the New Jersey coast all the way up and down in their flights. At night they fly high, and when they see Absecan Inlet light, which is 167 feet above the ground, they head directly for it. They seem to be attracted in the same way that the moths which flicker around a candle are. If carried along by a heavy wind, they dart against the plate-glass windows surrounding the lens, and drop to the ground dead, bespattering the panes with their blood, to prevent which a wire netting has been constructed on the north and south sides of the lantern. Not long ago a large duck, which was sailing along in a furious storm, was dashed against this netting with such force as to indent it six square inches. When the weather is clear immense numbers of small birds hover about the light after dark, and then as soon as they have rested on

* Such a scene as that described is figured in Mr. Seebohm's "Siberia in Europe," p. 242; and from personal observations during an autumn residence on Heligoland, I can amply confirm the accuracy of this description, as well as of the earlier one by Mr. Cordeaux of a similar sight contained in his paper on Heligoland Ornithology (*Ibis*, 1875).

the rail surrounding it, fly off, but soon return again. A large snipe landed so violently against the wire-work that he plunged through one of the meshes, and stripped himself of all his feathers as far back as the shoulders.

In like manner the residents in the Frisian Islands, which form a breastwork to Continental Europe—and of which Heligoland is one—have fine opportunities of observing the practical outcome of this strange migratory instinct of birds. In September and October the church roofs of Sylt and Föhr and the Peninsula of Jutland are covered with vast flocks of thrushes and other migrants, drawing breath before resuming their southward flight; and on every church tower in Denmark, North Germany, and Holland, may be witnessed those solemn assemblages of storks which are held preparatory to the meditative birds taking wing for Tanganyika, Timbuctoo, or some other African watering-place.* The chimney swallow, which in October was twittering under the eaves of the manor-house in Kent, may possibly be recognising the squire as he suns himself in the Algerine town which they have both chosen for their winter quarters, and the night-

* Their nests may be frequently observed on the square towers or minarets of the mosques in Morocco. During our long ride from Fez to Tangier, in November, 1884, we noticed numbers arriving; and with such semi-pious respect do the Moors, Berbers, and Arabs treat "B'elharge," that not unfrequently the young ones might be seen perched on the backs of the sheep and cattle. They are emblematical of faith: to kill one would be sacrilege. These congregations of birds in council are, however, not confined to the stork. It is, indeed, common to find migrants so consulting over the journey to be taken. Many of my readers may remember the "Swallow Parliament" which meets on fine autumnal afternoons upon the dome and circular gallery of the Radcliffe Library, at Oxford.

Fig. 2.—ARRIVAL OF MIGRATORY BIRDS.

jar, which was in such a hurry to leave us that she had no time to build a nest, is, perhaps, a week after taking her departure from Surrey, comparing notes with its vocal rivals among those palmetto groves beyond which peep the minarets of the Great Mosque of Morocco. In July every Arctic cliff is moving with bird life; by October or November, at latest, the raven and the snowy owl are almost the only fowls left to give a semblance of the busy world to the snow wastes glittering under the cold moon and the weird-like northern lights.

This feverish desire to be off infects all those subject to it, no matter in what position they may be placed. Nearly every bird is, indeed, more or less migratory: that is, it changes its quarter to a certain extent according to the season of the year. Even cage birds, reared from the eggs of parents who never knew what freedom was, get as uneasy as a Londoner in August, and if their prison doors are left open, will sometimes desert their helpless young in order not to be too late for the winter hegira. The house martin (p. 58) has been known to do so repeatedly; and if the autumn is colder than usual, the swallow and the Carolina wax-wing will suddenly take their departure from Canada, leaving their callow brood to die of starvation, the instinct of self-preservation being evidently stronger than that of maternal affection. What is more—and there could be no better proof of the "migratory instinct," which the term indicates—the young of such birds brought up from the nest, and apart from their parents, display the yearning quite as conspicuously as do their own civilised brethren. Finally, as we have already hinted, the instinct

is variable, for the same species often migrates in one country and is stationary in another, or, as Mr. Darwin points out, different individuals of the same species in the same country are migratory or stationary, and these can sometimes be distinguished from one another by slight differences. The quail, for example, is migratory in South Africa, but stationary in Robben Island, only two leagues from the continent, and in Ireland the quail has lately taken to remain in numbers to breed there. In Germany, in addition to robins, there are migratory and non-migratory thrushes, the one being distinguished from the other by the yellow tinge of the soles of their feet. In the Falkland Islands, on the other hand, no land bird is migratory, and there is no migratory bird in Mauritius or Bourbon.

Yet, large and ever increasing though the extension of bird migration is, the causes which lead to this curious trait are very imperfectly ascertained. There is, of course, much speculation and many specious theories intended to dovetail into some still broader hypothesis, but sound inferences from well-confirmed facts are much rarer than one might have hoped after the years of observation which have been lavished on this department of biology. We know all about the spring and summer flights of the migrants—and their routes are singularly determinate—but we are still as ignorant of the motives of these fixed northern and southern journeys as we were before Palmen, and Newton, and Grebel, and De Serres, and Cordeaux, and Harting, and Adams, and Seebohm, wrote so learnedly on the theme. Of one thing we are certain: migration is

no new habit, either in birds, beasts, or fishes, for as long as history affords us any data to go upon there are references to this instinct; and palæontologists are now generally agreed that there are proofs of it having been practised ages before man came upon the earth. The "hawk that stretches her wings to the south" is a bird as well known and inexplicable, as regards this portion of her manners, as she was when Job pondered over her ways. Every autumn the water-fowl throng to the rivers of Asia in the same mysterious fashion that they did when Homer wondered from whence they came. "Anacreon's Song Divine" celebrated the coming of the swallow, but he did not tell why she came any more than can the last Nile boat traveller or the gentleman who annually favours us with a dissertation on the subject. The Greek children still celebrate the coming of the swallow as did the little Rhodians two thousand years ago in the rhyme preserved for us by Theognis and Athenæus, of which one variant may be thus freely Englished:

> "She comes, she comes, who loves to bear soft sunny hours and seasons fair:
> The swallow hither comes to rest her sable wing and snowy breast,"

just as the Hungarian boys rejoice over the vernal appearance of the stork on the islands of the Danube, or the Indian of the Fur Countries, in his rude calendar, names the "moons" after the birds of passage, whose arrival is coincident with these changes. But "who bids the stork, Columbus-like, explore heavens not his own, and worlds unknown begin? Who calls the council, states the certain day? Who forms the phalanx and who points

the way?" are yet, as in Pope's day, questions to which we can return no certain answer, though year by year we are approaching nearer and nearer to the wished-for goal.

The individual swallow, it is now ascertained, returns from the Canaries or North Africa to the very spot on which it built its little mud mansion the previous summer, and, according to the observations of the celebrated Jenner, marked birds were caught at their old nests every year for three successive seasons. This fact is so remarkable that, even after allowing that the swallow tribe are gifted with extraordinary powers of localisation, and that their summer homes are well defined, it is something wonderful to remember that a bird after seven months' absence can still have treasured up in its memory, through the varied fortunes and vicissitudes of two long journeys, the recollection of the landmarks necessary to guide it to and from its summer home. For many years in succession a pair of blue titmice built their nest in an earthenware bottle placed in the branches of a tree in a garden at Oxbridge, near Stockton-on-Tees, and even where the surface of the country has undergone a complete change, some species will continue breeding on the beloved spot. In America, orioles and vireos appear to return to the same tree, or even to affix their nest to the same branch, for many successive years; and in like manner, Allen has noticed how the wren, the pewee, and the robin, repeatedly occupy the same nesting sites. So mysterious did these facts—the sudden disappearance and equally unexpected appearance of birds—appear, that at one time it was believed that the nightingale, the cuckoo, and the corncrake hybernated,

as do bats and bears. Even up to comparatively late times many naturalists of deserved eminence favoured the absurd theory of swallows passing the winter in the mud at the bottom of ponds. We know better now, for as a famous zoologist remarked in regard to the coming and the going of the puffins, were they sea-fowl satellites revolving round the earth, their arrival could not be calculated with greater accuracy. Yet we are unwilling to leave the explanation among the somethings "in this earthly ball" which are to be "unriddled by-and-by."

In the first place, some of our old ideas regarding migration have been undergoing a considerable revolution. We have seen that migration in one form or another is a law of nature. Most birds and quadrupeds are more or less in the habit of changing their quarters according to the season of the year. Even the sparrow is migratory in some districts of the Continent, and in general terms it may be said that there are few, if any, birds of the northern hemisphere which do not in some degree practise this seasonable vagabondage.

Food, and the necessity for obtaining it, have been adduced as the principal causes of migration from north to south, or from east to west, and to a certain extent this is true. The birds which breed in the Arctic regions, and along the shores of Russia, Siberia, and the "barren lands" of North America, the snow buntings, the geese, the ducks, the turnstones, and a host of others, must necessarily seek milder latitudes if they are to live when the snow covers their feeding-grounds, while it is equally evident that insect-eating birds, like the swallow, cannot remain long

in regions from which insect life disappears for several months in the year. But this explanation fails when we come to the vernal migration, for it can scarcely be supposed that the swallow or the flycatcher would leave a region where there is perpetual summer, and winged food in superabundance, in order, after risking a long journey over land and sea, to find a greater scarcity of the same kind of proviant? It is equally improbable that the seed and fruit eaters who, since October, have been fattening amid the gardens of Algeria and Egypt should suddenly, in March or April, be possessed of such an inordinate craving for a change of diet as to fly three thousand miles on the chance of picking short commons in an English spring. Yet both here and in America the departure of the birds is regulated very strictly in accordance with the disappearance of the particular food on which they subsist. Thus—to take the United States—the swallows, swifts, and flycatchers are, with a few exceptions, the first to leave and the latest to arrive. Those which subsist on insects, but also affect, in part, soft pulpy fruits—the vireos, tanagers, and grosbeaks, for example—are almost as early in their departure and as late in their return as those which are exclusively insectivorous. In North America, we are assured by Mr. Allen, the great mass of the warblers and thrushes tarry still later, while the hardier seed-eating finches remain till the leaves have fallen and sharp frosts have seared the fields. The sandpiper, woodcock, and snipe linger till the oozy marshes and shores fail to yield their accustomed food, and the water-fowl abandon their summer haunts only when the cold hand of winter has locked

up in ice the inland lakes and rivers, or driven their finny prey to deeper waters. "The non-migrating species"—I am quoting the eminent American naturalist already mentioned—"as some of the woodpeckers, the omnivorous crows and jays, and the grouse, are there when food is of such a nature that the change of season only remotely affects the supply. As would be naturally inferred, the distance traversed by the migrating kinds in passing from their summer to their winter homes is in direct relation to their habits in respect to food; those wholly, or almost wholly, insectivorous, being not only the first to leave, but those which penetrate farthest south, only finding congenial surroundings in sub-tropical or inter-tropical regions."

At the same time, it would be a mistake to infer that size in any way governs migration, though length of wing may. The smallest birds often fly much farther than the biggest. The Swedish bluethroat performs its maternal functions among the Lapps, and enjoys its winter holiday among the Negroes. The blackcap consorts all summer among douce Presbyterians in Scotland, and all winter is at home among pyramids and mosques in Egypt, and the grey wagtail, which was in October the guest of a Kentish vicar, is by November twittering itself a welcome from the Hadjis of Mecca and Medina. The ruby-throated humming-bird proceeds twice a year from Mexico to Newfoundland and back again, and the cuckoo, which is much slower on the wing, will fly with ease from Northern Europe to Africa or the Persian Gulf. The stork, which is, on the other hand, the largest of the migratory birds, leaving the marshes of Holland, or the pleasant land of Denmark,

a few days later is seen in great flocks, making for some portion of Inner Africa. The capacity for taking such flights ceases to be a theme for wonder when we find that the common black swift is able to cover 276 miles an hour, a speed which, if maintained for about six hours, would transfer it from Surrey to the Soudan, and the purple swift of North America is affirmed to be even more powerful on the wing. The chimney swallow is said to be able to attain a rapidity of flight averaging ninety miles an hour; the ordinary carrier pigeon has been known to fly from Paris to Bordeaux—distant in a straight line 300 miles—in seven hours, while we have the authority of a naturalist, who has so attentively studied the bird life of North America as the late Professor Leith-Adams, for affirming that the passenger pigeon travels at the rate of about one thousand miles a day.

It is therefore clear that while food is one of the prime stimuli which impels the migrants to leave the north in autumn, we must seek for some other causes to explain why in spring they return from winter quarters, where every description of nutriment is so abundant, to one where it exists only in small quantities. It has no doubt been advocated that birds leave their winter quarters because in southern climates the heat dries up everything and lessens the superfluity of insect life. This, unfortunately, is not the experience of the traveller, who is tortured by mosquitoes and all other winged pests, or of the farmer, whose crops are devoured by grasshoppers, or of the gardener, whose plants are preyed on by aphides and beetles, or of the olive-grower, who is sometimes at his

wits' end for a means of destroying the insect plagues which descend on him. In reality, in all tropical countries, there are endless varieties of insect-eating residents, and even in Greece, where several swallows winter, one variety is found there all the year round. It may also be added that in the north there is not always food for the second comers to the same district, and that in consequence the weaker are driven away by the stronger, a circumstance which aids in the gradual movement from north to south, and *vice versa*. In Düsseldorf flocks of swallows arrive early in April, circling over the town like a swarm of bees, but we are told by Mr. Seebohm that in May the swifts appear on the scene and soon become as abundant as the swallows were, whilst the latter birds are rarely seen during the summer. Food, therefore, though among birds, as among all created beings, the *primum mobile* of emigration, is also insufficient to explain the theme of this paper.

Temperature has unquestionably much to do with the vernal and autumnal shifting of quarters, though what is the exact connection between the arrival of the migrants and that of the weather we cannot say. An early winter or a late spring hastens or retards the emigration and immigration of birds, and hence, to a limited extent, geese, ducks, and similar arrivals from the north, deserve the popular esteem in which they are held as harbingers of severe weather, for cold comes from the north, and where it hardens the soil or freezes the water out of which these birds devour their food, they must necessarily leave earlier than they would otherwise have done. But, as Mr. Newton very justly remarks, they often arrive with the very weather they are

held to prognosticate, while sometimes this does not follow their appearance. It is, however, too sweeping a conclusion to infer that birds have no ability to discern approaching storms. From a vast series of facts accumulated, especially in America, it is clear that the southward emigration of geese and other water fowl "usually precedes, often by only a few hours, the approach of heavy storms, and a sudden and very great reduction of temperature, which they often avoid by keeping in advance of the change." It is also well known that many birds display restlessness just before the occurrences of severe storms, and that some, which are not migratory in the usual sense of the term, move southward in large flights, as if preparing to avoid the tempests brewing in the north. Some birds are more hardy than others: the swallow is particularly tender. The tiny wren lives through the Scottish winter.

But after allowing that the migrants which come and go with such regularity can regulate their movements in an appreciable degree by the rise and fall of the mercury, it still remains to be explained why they leave the mild south for the inclement north. The hyperborean ranges which they claim for their summer residence are, perhaps, the best for their nesting functions; yet it puzzles us to understand how this fact has become so deeply impressed on the bird's brain that it experiences an irresistible desire to return after the lapse of a definite interval, unless, indeed, on the unavoidable conclusion that this is due to a blind instinct, or that the old birds have the power, as no doubt all the higher animals have, of communicating their experience to the younger members of their species.

And this leads us to consider how far the passion for *procreation* influences the migration of the feathered race. The breeding stations of birds are their true homes ; their winter residences are only their halting-places during the "off-season" of the year. But it is stretching a point to suppose that in returning to their birthplaces the migrants are influenced by that "nostalgia" which the wanderer displays when, forsaking the lands of everlasting summer, he returns to the uninviting spot in the bleak land which is associated with his earliest recollections. A more reasonable hypothesis—though like many conclusions of a similar character one incapable of demonstration—is that birds, like other animals, have implanted in them an instinct which tells them that now is the season for mating, nest-building, and egg-laying. And, as if confirmatory of this speculation, it has been noted that the young, or immature birds of some species which require several years to attain maturity, pass the summer at points far to the southward of the usual southern limits of the breeding range, while in other cases there are laggards which, according to Mr. Allen, who has particularly noted it, arrive much later than the fully matured birds. Still, here as elsewhere, there are objections to the complete acceptance of a theory which is compelled to depend so much on the faculty of instinct, since there is more written than is understood about this mental manifestation. Here is one. The parental duties are supposed to hasten the spring departure, but there is nothing to justify us in asserting that birds show the least disposition to pair before they make each other's acquaintance in their summer haunts. The birds of the southern regions are as migratory

as those of the northern. Many species visit New Zealand, Australia, and South America only during the breeding season, and though the tropical birds prefer for the most part to nest there, the chances are that, if we include in birds of the torrid zones those species which visit them "after having bred in the cooler regions, they will also contain a considerable proportion of migrants even though no bird migrates there to breed." "We might lay it down as a law," writes Mr. Seebohm, "that every bird breeds in the coldest regions of its migration." No bird migrates to the tropics to breed because there is no hotter region for it to migrate from; and he holds that "well-authenticated stories" of birds breeding a second time in the place of their winter migration is akin in scientific value to the tales of swallows having been found hybernating in caves or hollow trees, or of toads having been found in the recesses of otherwise solid rocks. And here it may be noted that, in addition to the two regular migratory waves—one north-east in spring and the other south-west in autumn—there is yet, quite independently of these, a continual stream of immigrants, week after week and month after month, to the eastern shores of these islands, coming directly across Europe from east to west, or more commonly from points south of east to north of west, and the reverse in spring. These immigrants are mainly composed of well-known species which annually make these islands their winter quarters, and as a rule take the place of our summer birds. They come in one broad stream, but denser on some special lines or highways than others. "Cutting the line of ordinary migration at nearly right angles, one

flock brushes the Orkney and Shetland Isles, passing through the Pentland Firth, even touching the distant Faroes. The southern wing crosses the Channel Islands, shaping its course in a north-westerly direction to the English coast." *

And now we come back to the place whence we set out. Granting that birds are impelled to migrate, by some irresistible instinct, when was the instinct first acquired, and if not innate from the beginning of time, what was the cause which first led it to be acquired as a factor in the struggle for existence, since it requires but a brief study of nature to see that every action of animal life is more or less dictated by the desire for self-preservation? At one time it was supposed that birds in flying from the north took no very determinate course, and especially that in crossing the sea the line followed one year was not, unless accidentally, the same as that adopted in the next. We now know this to be a mistake, for Herr Palmen, a Swedish ornithologist, has with infinite industry and long observation determined that birds in their migration wing their way over the same route year after year, even though a different one might be shorter and therefore more convenient. These routes so far as the region studied goes, are as follows, and without pinning our faith to the exact details, it may be said that with a few exceptions nearly every naturalist is agreed as to the general facts.

The first route is that which, leaving the Siberian shores of the Polar Seas, Novaia Zemlia and the north of

* "Report of the British Association Committee on the Migrations of Birds," 1883.

Russia, passes down to the west coast of Norway to the North Sea and the British Islands. The second proceeds from Spitzbergen and the adjoining islands, and follows much the same course, but it is prolonged past France, Spain, and Portugal, to the west coast of Africa. The third begins in Russia, threads the White Sea, and the Lakes of Onega and Ladoga, skirts the Gulf of Finland and the southern part of the Baltic, and to Holland, *viâ* Holstein, where it divides, one branch uniting with the second-named route, while the other, running up the Valley of the Rhine and crossing to that of the Rhone, splits up on reaching the Mediterranean, where one path passes down the western coast of Italy and Sicily; a second takes the line by Corsica and Sardinia, and a third follows the south coast of France and the eastern coast of Spain, all three paths ending in North Africa. The fourth route, as well as the fifth and sixth, all set out from the extreme north of Siberia, but after this take divergent courses. For instance, the fourth, ascending the river Obi, branches out near Tobolsk; one track diverging to the Volga, descends that river, and so passes to the Sea of Azof, the Black Sea, and thence by way of the Bosphorus and Ægean to Egypt. Another track makes for the Caspian, by way of the Ural River, and so leads to the Persian Gulf, while two more are lost sight of on the Steppes. The fifth mounts the Yenessei to Lake Baikal, and thence into the plains of Mongolia. The sixth ascends the Lena, and crossing the Upper Amur reaches the Sea of Japan, where it combines with the seventh and eighth, which run from the eastern portion of Siberia and Kamschatka. The ninth leaves Greenland and Iceland,

passes the Faroe Islands to Britain, and then joining the second and third routes run down the French coast.* It is the same in America, though, owing to the less settled character of much of the country, the routes have in the New World not been so accurately determined as in the Old. Seas such as the English Channel and the Mediterranean are no barriers to the migrants, though in crossing the latter they do so in three routes: by the South of Spain, near Gibraltar, by Sicily over Malta, and by Greece and Cyprus. Furthermore, on examining some of the other routes taken, it is found that they pass over the lines of shallowest water, pointing out where in former times a long since vanished land connection existed. At a comparatively recent period, the Mediterranean seems to have consisted of two lakes, Europe and Africa being connected by way of Spain and Italy. At this period in the world's history, Great Britain was evidently in union with the Continent, so that birds which now cross two seas on their annual migration might have acquired the habit at a time when no such sea existed. They travelled by these land bridges so long that when they gradually disappeared, the birds having acquired the habit, transmitted it as an instinct to their descendants, and continue to do so though the sea has for unnumbered ages rolled where prior to the Tertiary period, or perhaps well into that era, there were undulating plains. Mr. Wallace, who was the first to formulate this theory of the origin of migratory habits, has so concisely stated its leading principles that it may be

* "Om Foglarnes flyttningsvägar" (1874), or Professor Newton's summary, which has been followed.

well to quote his exact words. "It appears to be probable," writes this eminent biologist, speaking of the question under discussion, "that here, as in so many other cases, 'survival of the fittest' will be found to have had a powerful influence. Let us suppose that in any species of migratory bird breeding can, as a rule, be only safely accomplished in a given area; and further, that during a great part of the rest of the year sufficient food cannot be obtained in that area. It will follow that those birds which do not leave their breeding area at the proper season will suffer and ultimately become extinct; which will also be the fate of those which do not leave the feeding area at the proper time. Now, if we suppose that the two areas were (for some remote ancestor of the existing species) coincident, but by geological and climatic changes gradually diverged from each other, we can easily understand how the habit of incipient and partial migration at the proper seasons would at last become hereditary, and so fixed as to be what is called an instinct. It will probably be found, that every gradation still exists in various parts of the world, from a complete coincidence to a complete separation of the breeding and the subsistence areas, and when the natural history of a sufficient number of species is thoroughly worked out, we may find every link between species which never leave a restricted area in which they breed, and live there the whole year round, to those other cases in which the two areas are absolutely separated."

This explanation of the origin of the migratory instinct, and the reason why birds take certain determinate routes over the sea, is in perfect agreement with the conclusion

at which Mr. Darwin arrived at an even earlier date, though the facts were not published until after his death. Instincts, he shows, can be acquired. Birds which were once perfectly fearless of man now display the usual terror, since the oceanic islands which they inhabit have been visited or settled, and transmit their prudent instinct to their offspring. On the other hand, while at first frightened by passing railway trains, they soon learn that these novelties betoken no danger, and so in time the birds alongside the lines view them with the most perfect equanimity. The sheep, which in Spain are taken every summer to pastures in another part of the country, acquire, by-and-by, an instinct for this artificial migration, which is displayed by curious uneasy motions, so strong that about the time when they ought to be off it requires all the vigilance of the shepherds to prevent them escaping, and there are cases in which the journey has been performed, the animals reaching their old feeding-grounds without assistance. Certain savages—the North American Indians and the Australians, for example—have this instinct in almost as great perfection, for it is usually said that they will find their way from one part of the country to another in a manner perfectly wonderful. I have reason to believe that the stories about their capacity in this respect are exaggerated; but it is not quite correct to affirm that this faculty only exists as regards their own part of the country, and that, therefore, it is simply experience, for they display it in almost as great perfection in any part of the region which they inhabit, though they were never there before; and Wrangel has noted with admiration how

the Tuski of Siberia guided him through an intricate labyrinth of hummocks of ice with incessant changes of direction. Now, it is impossible to believe that they could have been acquainted with every spot on an ice-field which forms and is destroyed within twelve months. Yet, while Wrangel was watching the different turns, compass in hand, and trying to reason the true route, the natives had a perfect knowledge of it instinctively. How far this is the case with birds, or how much of their power of guiding themselves over seas is due to experience and observation, we shall see presently. But that the migratory habit, as like other habits, becomes acquired until it becomes an instinct, there need be no doubt, and that the explanation of how this instinct was acquired may be accepted until the progress of knowledge renders both theories no longer tenable. "Take," remarked Mr. Darwin in the latest published of his writings, "the case of a bird being driven each year, by cold or want of food, slowly to travel southward, as is the case with some birds, and in time we may well believe that this compulsory travelling would become an instinctive action, as with the sheep in Spain. Now, during the long course of ages, let valleys become converted into estuaries and then into wider and wider arms of the sea, and still, I can well believe, that the impulse which leads the pinioned goose to scramble northward will lead our bird over the trackless waters, and that by the aid of the unknown power by which many animals (and savage men) can retain a true course, it would safely cross the sea now covering the submerged path of its ancient land journey."

That migratory birds know the position of the magnetic pole is a hypothesis too absurd to be worthy of a moment's discussion; and it is not much less difficult to understand that they guide themselves over broad oceans, and are able to find the nest in the hedgerow round which they twittered six months before, simply by the aid of a highly-developed instinct for locality. Yet this is the only hypothesis which we can accept, though how they can distinguish north and south is not quite so easy to comprehend. It must not, however, be supposed that the course of migratory birds is "unerring." They frequently lose themselves. Of the millions which begin the flight from the northern breeding-grounds, a comparatively small number reach the winter quarters. Tens of thousands are every autumn drowned, and when the night is dark they seem at a loss how to proceed, alighting in prodigious numbers on such spots as Heligoland. They may sometimes be seen hovering in great flocks over towns, uncertain what the blaze of light means, and, as we have seen, vast numbers are killed by flying against the lighthouses they encounter in their perilous journey. Migration is, indeed, so fraught with mortality to the migrants, that it has been suggested one of its chief purposes is to keep down the increase of bird life, which would otherwise be so enormous as to become a positive danger to the other inhabitants of the world. Dismissing this application of the doctrine of final causes as a little too far fetched; there cannot, nevertheless, be a doubt that migration is not accomplished without a great proportion of those that take part in it perishing before they have proceeded far on their journey.

Experience plays a part in piloting birds during their journey, which until recently was not fully recognised, the "mysterious unerring instinct" being a doctrine too alluring to be deposed in favour of any such everyday fact as this. Yet, even those who do not quite accept Herr Palmen's assertions about determinate routes, and go so far as to declare that in America, at all events, the spring and autumn ones are different, and that the comparative scarcity of birds by one route one year, and their abundance the next, indicates that the lines of migration vary, are ready to accept the idea that birds acquire and transmit their geographical knowledge of the journeys they make. They do not always fly straight to the goal, as would be the case were they guided in their course by an unerring instinct. They follow well-marked physical features, the windings of a river, a valley, or a coast-line. That birds possess remarkable memories for direction and locality is proved by their being able to find their carefully-concealed nests in reeds, marshes, thick hedgerows, dense forests, or grassy prairies, after flying away for a long distance to feed, and, as we have seen, swallows and birds of prey return year after year to the same nests, herons to the same swamps, and even the same trees, and many sea-fowls, like cormorants, terns, and gulls, to the same stretch of sandy beach, or rocky cliffs, abandoning them only after a long course of ceaseless persecution from man Birds which make their migrations over continents do so in a leisurely way. They tarry here and there, resting themselves, and studying the lay of the land. Their sight is, we know, preternaturally keen, and they can, in consequence, fly with ease between landmarks which to our less

perfect vision seem hopelessly far apart. Even birds which fly over seas are not without guiding-lines. Those which make such journeys generally take islands like the West Indies on their route, and when they visit the Bermudas from the adjoining continent, as the roaming plovers and sandpipers do, they are able by their strength of wing to make the passage quickly, and may possibly find guidance in the sun, in the prevailing winds, or, as has been suggested, in the change of temperature attending change of latitude, even when their sharp eyes cannot, from an elevated position in the air, scan the lofty coast they are bound for.

So far good. Still, after all has been said, there remain many difficulties. Birds, we know, are very easily deceived. The lark will soar on a January day provided the sun shines with a summery glare, and thrushes may sometimes be heard singing in December or January, provided the weather be mild. In the winter of 1883-4, a starling's nest with a young brood was found, though the same bird must have had another in August or September, the bird being unquestionably deceived by the spring-like climate of the early winter months. On the other hand, D'Orbigny declares that a lame hawk in South America knew the period of three weeks so accurately that it used, at this interval, to visit the monasteries where food was distributed to the poor. But memory, or even the most elementary experience, can have no part in the young cuckoos' start for the first time, two months after their parents have departed. Again, if experience was the only guiding power of birds during long journeys, it would naturally follow that the old birds would accompany the young ones. But the very contrary

is the case. The young and the old always travel separately, and the fledglings form the van of the southern migration. Mr. Gätke, Colonial Secretary of Heligoland, who has perhaps the best opportunity of any ornithologist for observing such facts, asserts that of the 360 species of migratory birds which he has himself taken on the island, in one case only did the old birds precede the young in the autumnal flight. In all others, the young got the start of their parents by some weeks, the old males, who so often lead the hegira, being the last to migrate. The one exception is the cuckoo, the old birds in this case winging their way south or north before the young, which they had left to be brought up by a stay-at-home foster-mother. The contrary arrangement is observed during the vernal migration. In spring the first flocks consist principally of adult males. The second week's arrivals are composed mainly of adult females; in the third week follow the birds of the year; and finally, during the last week of the northward migration, come the cripples—birds which have lost their toes, or a whole foot, birds with half a tail, birds with one portion of the beak abnormally long, or birds with some other physical defects. In autumn there is also a visitation of the maimed and the halt to Heligoland, some weeks before the regular migration is due. These individuals Mr. Seebohm describes as in various stages of plumage—summer, or winter, or in the transition stage between the two, and moulting as they go. These *avant-courriers* who loaf about for a few days in a desultory sort of way, are supposed to consist of barren birds, and birds who have been unable to find a mate, or birds whose nests have been destroyed too

late in the season to allow of a second nest being made. "Having nothing else to do, the hereditary instinct to mi-

FIG. 3.—THE CORN-CRAKE (*Crex pratensis*).

grate not being checked by the parental instinct, they yield to its first impulses, and drift southwards before the general body of the species."

Here, therefore, is a difficulty which, on the theory of

experience, is hard to get over. Experience, however, Mr. Wallace will have it, exerts a great influence over all animals. He will even hint that one bird learns how to build its nest from another, and that until some great garden is netted in, and then, various birds reared from eggs in confinement, turned out with enough of raw material to work with, we shall never be able to say how far the "instinct" for building their homes after a certain fashion is innate or merely a form of art quickly acquired from observation.

The subject is, therefore, not quite so easy as the glib formulation of mechanical theories would have us to suppose. Nor is it a simple matter to explain offhand, or to fit into any one of the popular systems of the day, the fact of certain birds in certain families staying at home and others which might seem equally well able to bear cold, and which subsist on the same kind of food, migrating with the utmost regularity. The birds which have the most northern range in summer have, it has been affirmed, the most southern range in winter also, and that this wide flight depends on the superior power of wing possessed by the individuals in question. It may, therefore, be possible that the fact of the old males preceding the migration in spring may be due to their greater strength, and that if the young birds are the advanced guard in autumn, this is only at first, the observer in places like Heligoland being too near the starting-point of the southern flight to judge whether this inequality in the speed of travel is permanent. Still these are the facts, and unless they are refuted by others equally strong, they form an insuperable barrier to the easy flow of the kind of "explanations" vouchsafed. In any case,

if experience goes for much, that the young birds should be started off ahead of their parents is an eccentricity which we should not have expected.

These are the principal data known about the migration of birds, though so extensive has the literature of the subject become,* that a volume would not suffice to digest all that has been ascertained regarding this peculiar trait of the feathered tribes, not to mention the same habit in certain mammals and fishes. It will have been seen that it is surrounded with difficulties. So far as at present known—to sum up the results in a few words—it resulted from changes of climate occurring at a geological period dating from the close of the Pliocene epoch. It has been ascertained that there is every gradation of the habit, and that representatives of the same species may be sedentary or roving "according as they inhabit the northern or southern portion of the common habitat." Food and cold compel the birds to remove south, and the procreating instinct to shift their quarters to the north. It is believed that they pursue definite routes, though whether guided by inherited experience, instinct, memory, or eyesight, is still a problem which only the future can solve. Observations—always observations—are what is required, and so long as these are accurate, and recorded without reference to pre-conceived ideas, they will form welcome additions to our ever-accumulating pile of data.

* I have not thought proper to distract the reader's attention by detailed references to these authors. The principal have, however, been mentioned, and in addition to the information derived from them, the writer has availed himself of much personal observation in many parts of Europe, America, the Arctic regions, and North Africa.

SNOW.

By Geo. G. Chisholm, M.A., B.Sc., F.R.G.S.

Every one knows that snow consists of frozen drops of water, that it is in fact made up of minute particles of ice. Every one knows also that though made up of frozen drops of water, snow never falls in round globules like rain. The irregularity in the shape of a snowflake would probably, indeed, be one of the first points of distinction that would strike an ordinary observer in comparing it with a raindrop. Yet the truth is that snowflakes, though indeed different in form from raindrops, have a regularity of their own just as perfect and far more wonderful than that which characterises unfrozen drops of water falling through the air.

This regularity, however, is usually concealed by the manner in which the snowflakes fall. In our islands snow falls as a rule when the weather is comparatively mild for winter, when the temperature of the lower air is near or even above the thawing point; and though the air is generally calm at the time it is seldom so absolutely still that the feathery flakes are not driven more or less out of their course in their fall. This being so, the different snowflakes are driven into contact with one another, and when the temperature is near the thawing-point, they then readily unite into one. Hence it happens that the snowflakes that fall to the ground in an ordinary snow-shower are not those

originally formed in the higher regions of the atmosphere, but irregular little masses of such, which have been aggregated together by frequent collisions in the lower strata.

Sometimes, however, the air is so still during a snow-shower that the particles of ice fall to the ground just as they are formed, and this is especially apt to be the case when the temperature is so low that they do not readily unite even when they strike against each other. The beautiful and wonderful regularity that distinguishes the structure of the particles is then apparent at a glance. Each one of them is then seen to consist as a rule of a little star of six rays, exhibiting the most perfect symmetry. The rays are all of equal length and are all inclined to each other at the same angle. This angle must necessarily be one of 60°, since all the six angles formed by the meeting of the six rays make up the 360 degrees that form an entire circle, and each angle is therefore one-sixth part of 360 degrees.

But these stars are seldom made up of simple lines proceeding from a centre. They are adorned in the most various ways, but however various the forms may be there is always the same symmetry in the adornments as in the ground plan. If one ray is adorned by feathery projections on each side, then all the other rays are adorned by precisely similar feathery projections; and in whatever way the rays are varied, they always correspond exactly with one another.

Such symmetrically-formed snowflakes are known as *snow-crystals*. These exhibit the most extraordinary variety. Scoresby, the Arctic navigator, enumerated ninety-

six varieties of form belonging to five leading types, and since his day upwards of a thousand forms have been described.

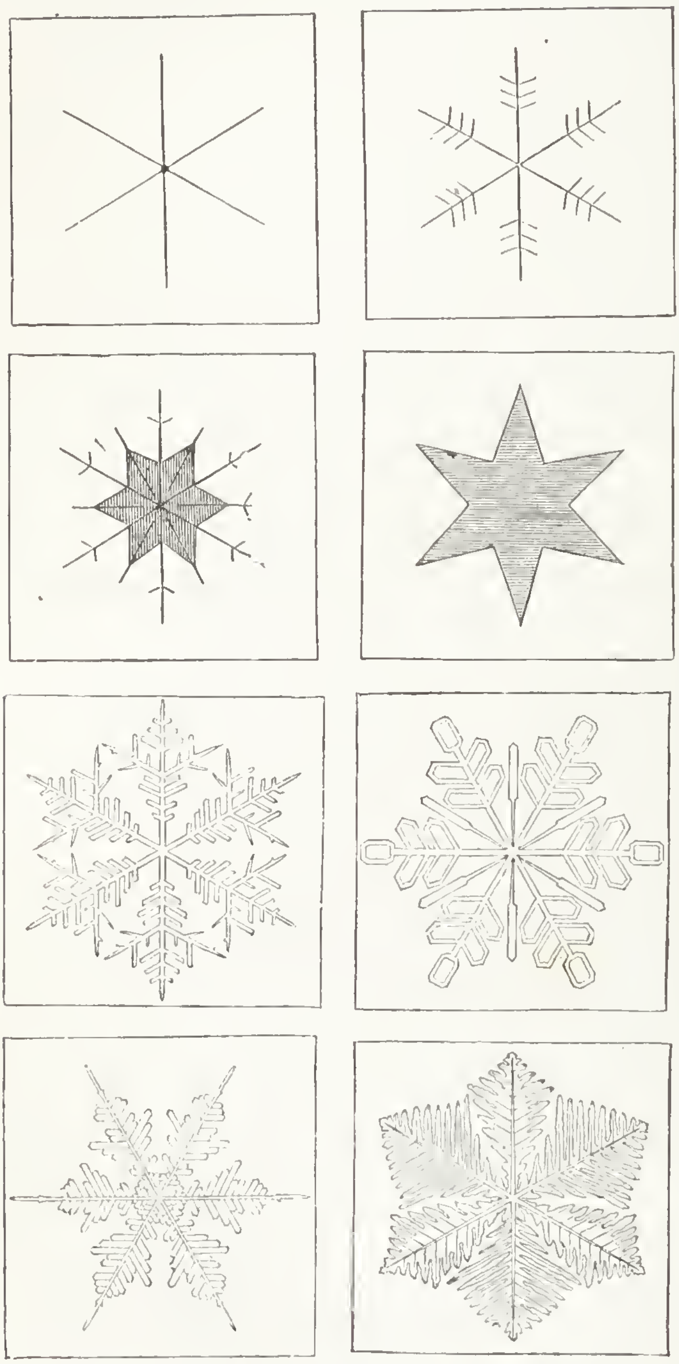

FIG. I.—SNOW CRYSTALS. (*After Glaisher.*)

Notwithstanding all this variety it is curious that in the same snow-fall the flakes generally assume only one form and seldom more than three or four. Whether it be the temperature, or the relative quantity of moisture in the air at the time of the snowfall, or other conditions which determine the precise form which the snow-crystals assume, that form does seem to be due to conditions which remain constant, or nearly constant, during the same snow-shower. That temperature has something to do with it seems to be proved by the fact that

a change in the form of the snow-flakes has been observed to ensue on an alteration in the temperature of the air.

Snow-showers in which the beautiful form of the individual flakes can be perceived at a glance, though they do occur, are not very common. Tyndall and various other observers have recorded cases in which they have witnessed such snowfalls, but they are so rare, especially in our own country, that it is not at all surprising that we should think of snow only as composed of irregular fleecy particles. For all that it would be a mistake to suppose that it is necessary to go to Canada or the Alps in order to observe the exquisite forms that snow-flakes assume. Even at home it is necessary only to observe more carefully, to see on our coat-sleeves forms as beautiful as are to be seen where different climates prevail. The fundamental structure is always there, even though it may be concealed through the accidents to which the flakes have been subjected in their passage through the atmosphere.

But even where the particles of snow reach the ground in forms that are perfectly regular, they do not always exhibit the extraordinary beauty by which they are often characterised. On the tops of mountains and in high latitudes, where the snow falls through air at a very low temperature, the particles may take the form of extremely delicate needles, or may seem to resemble a fine white dust. But these needles, on a close examination, are found to be minute six-sided prisms, the sides of which are inclined to one another at precisely the same angle as would be formed by two lines joining the ends of three adjoining rays in an ordinary snow-flake; and the particles of snow-dust may

generally be found on examination with a lens to show at least the minute beginnings of rays such as are seen in more elaborate forms. Some of the beauty may be wanting, but the exquisite mathematical regularity is always there.

It is this regularity which makes the form of a snowflake more wonderful, as we have said, than the form of the raindrop. Wonderful it will always remain, even though science should ultimately be able to explain the general laws under which particles of water assume this form in freezing. People are apt to think that when the scientific explanation of a fact is given the fact in question ceases to be wonderful. But if we would but reflect, we should see that this explanation is only another fact of a more general kind, and one which ought, therefore, to be regarded as more striking, one which ought to incite us to more curious inquiry. That a stone, dropped in the air, falls to the ground, is so familiar an experience that it could excite wonder only in the most reflective minds. But when it did excite wonder and curiosity, the fact was made not less, but much more wonderful when its scientific explanation was furnished in Newton's law of gravitation; a law according to which we find that a stone is, as it were, drawn to the earth by a force which can be measured, and by which the earth acts on the moon precisely in the same way as it does upon a stone dropped in the air. That explanation is a very wonderful fact, one that leads men of science to inquire why this should be so, though it requires a scientific training to appreciate that kind of curiosity.

The same would be the case if men of science would state for us the laws under which freezing particles of water assume the definite forms they do. But this is still beyond the reach of their knowledge. So far, almost all they can tell us with regard to this matter is that the regularity in the form of snow-flakes is far from being an isolated fact in nature, but that, on the contrary, it is one of the commonest phenomena Nature has to show. They can point out to us, for example, that this regularity of structure is not confined to particles of water which freeze separately in the air, but also to water frozen in the mass, to what is called *ice* as distinguished from *snow*. To prove this was not easy. Pure ice is as colourless and transparent as glass. When we look through it we see no evidence of what is called structure. We see no arrangement of parts built together so as to form the mass; we see apparently nothing but a perfectly homogeneous body. Moreover, when we break ice it falls into *irregular* fragments, in which we can trace no signs of a regular structure any more than we can by looking through it.

Still *there is* a way of showing the regularity in the structure of ice, a very simple and ingenious method devised by Professor Tyndall. His plan is this: he takes a slab of ice and causes a ray of light to pass through it at right angles to the surface of freezing, and then fall on a white screen behind. Now this ray of light is accompanied by heat, and the heat serves partially to melt the ice through which it passes; but it does not melt a hole right through the ice: it melts a particle here and a particle there, and

in doing so reveals the structure that was previously undiscernible. By melting a particle here and there the transparency of the ice is interrupted, and the screen now reveals a number of figures known as *ice-flowers,* each of which has a bright spot in the centre, and, like a snow-crystal, has six rays, inclined to one another at precisely

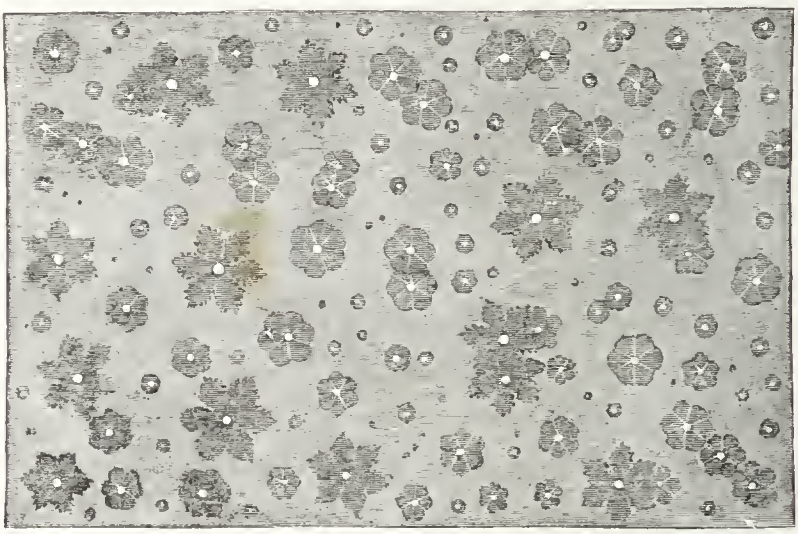

FIG. 2.—ICE FLOWERS.

the same angle, and variously adorned with symmetrical outgrowths.

It is not merely in solidified water that this definite structure is displayed. Under favourable conditions all substances, all the elements and all their inorganic compounds, assume such a structure in passing into the solid state. The parts composing such solids are all called *crystals* from the Greek word for ice (*krystallos*), and the structure itself is called *crystalline.* Such a structure is often revealed by the fact that the substance breaks more readily along the faces of the crystals than in any other

direction, and when such is the case the substance is said to have a *crystalline cleavage.* Frequently the crystalline form is obvious on the surface, and even where this is not the case there are other ways, besides that of cleavage, by which it may be detected.

It must not be supposed that all crystals are of the same type as those of snow and ice. The different types are indeed very numerous, but there are a few great facts which have been shown to hold good of all crystals, and to one or two of these it will be worth while to direct attention.

In the first place, all crystals have either three or four primary "axes" to which their form is related. To understand what is meant by the axes of crystals and how their form is related to them is important. The axes are imaginary lines intersecting one another in the middle point of the crystal, and so situated that by following them we can conceive the crystal as divided up into a number of similar parts—four when there are three axes, and six when there are four axes. Thus, if we take a crystal with three axes and imagine it to be divided into two by a plane passing from top to bottom along one axis, and from end to end along a second, then the third will be divided into halves; and if each half of the crystal be next divided into halves by planes passing through half of the third axis, then we shall have the crystal divided into four parts exactly equal in size and exactly similar in form. We thus see that the axes are lines with reference to which the parts of a crystal are symmetrically arranged.

Secondly, all crystals of the same kind, that is, formed

by solidification of the same substance *under the same conditions* have the relative values of the axes constant. If the axes are all equal in length in one crystal, then they are all equal in length in all the others; if one is longer than the other two or three, then in all the rest the corresponding axis is longer than the others in just the same proportion. But under this limitation there may be many modifications in the form of the same kind of crystals, and as to size there seems to be no limit whatever. Crystals of the same kind may be so small that they cannot be seen without the aid of a microscope, and so large as to weigh between 200 and 300 lb.

The same substance may, however, crystallise in one form in one set of circumstances, and in a form of a totally different type under other conditions. Several of the elements do so. Carbon, for example, crystallises in one form as the diamond, in another as graphite. Sulphur likewise has two crystalline forms, and so also have phosphorus, silicon, and some others. But more commonly it is found that one substance always crystallises in one form, and very often different substances crystallise in the same form. When this happens it is frequently possible to get two such substances to crystallise together into one lump, the separate crystals easily fitting into one another; and, what is still more curious and interesting, it is sometimes found that two substances forming crystals of nearly though not quite the same form will crystallise together, the crystals then being intermediate in form between those proper to the substances crystallising separately. The crystals have thus a certain power of *mutual accommodation*,

in spite of the exactness with which they habitually maintain their own form.

Such are some of the general facts that have been found to hold good regarding crystallisation. The explanation of these facts, as we have said, is still to seek. But though science has not yet succeeded in offering a complete explanation of the forms of crystals, it is yet able to point to an analogy which may guide us in looking for one.

Tyndall lays great stress on the analogy of the magnet. He asks us to observe that the power of the magnet is concentrated in its two extremities and is wholly wanting at the middle. Either end will attract iron filings, one end will attract and the other repel the north end of a suspended magnet, while the middle point has no action in either case. Divide your magnet into two, however, and then you find that you have two magnets which behave precisely in the same way as the undivided magnet did. What formed the middle or inactive portion of the large magnet is now as active as the two extremities, and the inactive portions are now situated midway between the ends of the two halves of the original bar. The same thing holds true, however minutely the magnet be divided, and physicists consider themselves entitled, and, indeed, bound, to infer that no limit would be reached till we got to the molecules, or ultimate particles, of which the magnet is composed. It is in these molecules, they believe, that the magnetic force must be found in the last resort; and these molecules therefore must have antagonistic properties at their two ends. Minute as they are, so as to be beyond the range of the

most powerful microscope, and not capable of being discerned by any of our senses, we must still conceive of them as having a certain length, and as having each a north end and a south end, with the properties characteristic of a magnet a foot in length. As the force displayed by them is exercised at two ends or poles, they are said to be bi-polar, and it is by the mutual action of the innumerable molecules contained in it that a large bi-polar magnet is formed.

Now we may imagine that crystals are similarly built up of molecules with definitely localised powers of attraction and repulsion, and that it is to this fact that they owe their definiteness of form. That such is the case can, indeed, hardly be doubted; but what there is in the molecules of a magnet, or of freezing water, to give them polarity of one kind or another is still unknown, and may for ever remain so.

These beautiful forms of the snow "crystals" have led us far, and we must not forget that there are other things worthy of attention to be observed in snow. First of all we will notice what no one can fail to have observed, the extreme lightness of this substance. We are all familiar with the way in which the flakes, in falling, are driven about by the slightest breath of air, and every one knows, likewise, that a handful of snow is perhaps as light a handful as one can lift. The actual weight of snow depends very much upon circumstances. Snow varies greatly in compactness, but on an average it is found that a cubic yard of this substance weighs about 187 lb., or about one-twelfth of the weight of an equal bulk of water. Ice

itself is lighter than water, but in nothing like the same proportion; and a certain volume of snow would, on an average, have only about one-eleventh of the weight of an equal volume of ice. No one will be at a loss to understand the reason for it; it is so manifest that snow in the mass consists of innumerable little spicules of ice interlaced together, and having a great quantity of air enclosed in the meshes, that the lightness of this substance when compared with ice or water will not excite any surprise.

But there are other consequences of this composition that are not so obvious, and which are a good deal more interesting. How many are aware that it is to this circumstance snow owes the *whiteness* for which it is proverbial? Why is any substance white? So far as any answer can be given to the last question it is the answer involved in the Newtonian theory of light. According to that theory pure white light is composed of all the colours seen in the rainbow or the solar spectrum, and the colour which any object assumes to our eyes depends on the way in which that object deals with the compound light. Some of the rays may be absorbed by the object, and others may be reflected from its surface or pass through it. All may be absorbed and all may pass through. In the latter case the object is perfectly transparent, and when only some of the rays pass through, as, for example, only the red ones, then the object appears to us to be of the colour of those rays. In any case an object assumes to our eyes the colour of the rays which reach our eyes from it, whether these rays be reflected from its surface or transmitted through the object. Now as sunlight is white, when all the rays composing it

are reflected from any surface, the sensation of whiteness must be produced in us; and, conversely, when we see a white object, we must conclude that it reflects all the sun's rays. We must believe this, therefore, of snow just as of chalk or milk.

But in the case of snow something more has to be said. If we carefully examine any individual flake of snow, we see that the minute spicules of which it is composed are not a solid white, but *transparent.* Instead of reflecting all the sunlight that falls upon them, they allow nearly all the light to pass *through.* If that is true of the individual spicules, why should snow in the mass, even in very small masses, appear white? The answer to this question is furnished by another fact in optics. It is found that where light passes through substances of different density, even though these substances be each perfectly transparent, that is, capable of allowing the rays of all the different colours to pass through, yet some of the light is always reflected where the surfaces meet. The rays so reflected do not belong to any particular colour, but to all the colours composing the light. In other words it is a portion of the white light that is reflected. Now in passing through snow light is constantly changing from a medium of the density of ice to one of the density of air. At each surface of each spicule

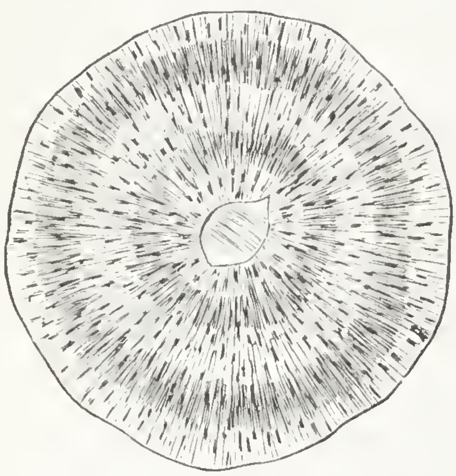

FIG. 3—A HAILSTONE WITH CONCENTRIC LAYER OF CLEAR BLUE AND OPAQUE WHITE ICE.

of ice composing the snow, a portion of the light is reflected, and the whole of the light is thus reflected before it makes its way very far through. Hence it happens that snow, though composed of transparent particles, is itself perfectly white, and at the same time absolutely opaque.

And snow is by no means the only object whose whiteness may be so explained. The explanation applies to all similar cases. A sheet of glass is as transparent as a slab of ice; but pound the glass into fragments, and you get a white opaque powder. Each of the little particles in that powder is still transparent, but the heap is not so. So, too, pure water is transparent, but when water is lashed into foam the foam is white and opaque. The foam is composed of thin films of water enclosing minute bubbles of air, and the light that falls on it must pass as far as it can alternately through air and water. It is just the same when water appears in the form of steam. Steam consists of minute globules of water dispersed through the air, and hence there is again the same alternation of media of different densities for the light to pass through. How white steam may be we all know from seeing it escape from the funnels of steam-engines, and how opaque it is we may perceive by considering the depth of the shadow which it casts on the ground on a bright day. It was one of Faraday's experiments to show on a screen the shadow cast by a jet of steam emitted in the path of a powerful beam of electric light, an experiment which he employed to illustrate the opacity of clouds of vapour, and the difficulty (and indeed the impossibility) of furnishing lighthouses with lights strong enough to shine far through dense fogs.

Let us now consider another consequence of the composition of snow. It is to the fact of its being made up of an interlacing mass of spicules with air enclosed in the meshes, that snow owes the property which gives it perhaps its chief value in the economy of nature. The property referred to is that of protecting the ground which it covers from the winter's cold. There are few who are unaware that snow does fulfil this function, but perhaps few, also, who realise the extent to which it does so. Were it not for the snow that regularly covers the ground to a great depth during the winter months in the Arctic regions, the hardy plants that flourish there would perish, hardy as they are. Pretty severe cold they must indeed be able to stand, but not the cold of the polar atmosphere, which is very much greater than under the snow. At Rensellaer Bay, in lat. $78\frac{1}{2}°$ N. it was found on one occasion that while the air was at a temperature of 30° below zero Fahr., the temperature at a depth of two feet was only 8° below zero, at a depth of four feet 2° above zero, and at a depth of eight feet 26°, or only six degrees below the freezing point of water.

The animals of the same regions partly owe their power of standing the winter to the same protective covering. Under the snow the lemming passes the winter, feeding on the stems of willows, and what other food it can find; under the snow the Arctic fox pursues the lemming; under the snow the female polar bear sleeps through the winter in a natural cell which goes on enlarging through the warmth of its breath.

But perhaps the most striking illustration of the pro-

tection which a covering of snow affords against cold is furnished by the way in which it was at last found possible to naturalise in gardens on the Continent of Europe some of the peculiarly beautiful and brilliantly-coloured plants of the Alpine regions, which it had often been attempted to naturalise in vain. During the winter they always died, till an ingenious gardener hit upon the device of affording them artificially the protection against cold which in their native seats they regularly obtain from their covering of snow. He did so by putting them in the greenhouses along with the orange and pomegranate trees of warmer climates, and his experiment was crowned with success.

The fact, then, that snow does afford a very efficient protection against cold is beyond question. But how does it do so? If there were a continuous covering of ice instead of snow the ground underneath would soon lose its heat and be reduced to the temperature of the air above, for ice is a sufficiently good conductor of heat. If there were no covering at all, the ground would lose its heat even sooner. But the air entangled in the meshes of the icy particles that form snow, renders the mass so bad a conductor of heat that the ground is able to preserve its temperature in the manner we have seen. It is just in the same way that furs and feathers keep the body warm. It is the air entangled among the hairs of the fur, and the barbs and barbules of feathers, that makes such coverings so bad as conductors of heat that the animals clothed by them are enabled to a large extent to defy the winter's cold. The difference between the average weight of snow and that of water, as given above, will enable the reader to conceive how much

air there must be enclosed as a rule within snow, and the amount is specially great in the snow that first falls in the Arctic regions. It is for that reason that, to use the words of Kane, the Arctic navigator, "no eider-down in the cradle of an infant is tucked in more kindly than the sleeping dress of winter about the feeble plant-life of the Arctic zone."

The protection which snow affords against cold is perhaps the most important function that it fulfils in the economy of nature, but it is not its only function, nor its only important function. In mountainous regions it accumulates moisture that might otherwise have fallen in repeated torrents tearing the soil from the mountain sides, inundating the valleys, and spending almost all its energy in destruction, and allows that moisture to be stored up for future use, to feed the streams that water the valleys and to keep them filled with comparative regularity and constancy. In level countries it performs a similar service in another way, keeping the underlying ground refreshed with water that trickles from the snow as it is slowly melted from underneath by the warmth of the earth itself.

In level countries especially, snow renders another important service to man in facilitating travel and the transport of goods. In this country we are not likely to think of snow from this point of view, for with us it is rather dreaded as an interruption to traffic, through blocking up our railway cuttings as it often does in the north. In the steppes of Russia, on the other hand, the snow season, before the introduction of railways, used to be awaited in order to allow of the easy carriage of goods from inland

towns to the ports of the Black Sea and the Baltic, and even since the introduction of railways the snow there adds greatly to the facilities for transport. In Northern Europe the Laplanders make long journeys in winter in their sledges drawn by reindeer; in Greenland and North America the Eskimo use in the same way their sledges drawn by dogs; in Canada the snow brings on the sleighing season, and thus affords the population the most keenly relished of the pleasures of winter.

Snow is not always our friend. We have just called attention to one mode in which it may be injurious instead of helpful, namely, through the interruption of traffic. That, however, is not the worst of the evils which it sometimes works. In thinly-inhabited countries there is no greater danger than to be overtaken by a heavy fall of snow or caught in storms of snow-dust, raised from ground on which snow has previously fallen, and whirled along by the wind. In such cases one's only safety is to make at once for the nearest human dwelling in sight. If there is none in sight the danger of being lost is great, for nothing so destroys one's sense of direction as the confused eddies of falling snow or swirling snow-dust.

In mountainous countries snow is attended by another danger. It accumulates on the mountain sides and may lie there till it gradually melts or evaporates; but it may fall in large masses carrying destruction along with them. Such sudden falls of masses of snow, snowslips as they might be called, are known as *avalanches*, and are of two kinds. In German Switzerland these are called respectively *Staublawinen* or dust avalanches, and *Rutschlawinen* or

sliding avalanches. It is difficult to say which is the more terrible when they occur in places where living beings or anything constructed by human hands may be in their path.

The former, the dust avalanches, occur in winter when the snow is powdery and little coherent. Successive falls of snow may have heaped up such accumulations that they are only just able to rest upon the slopes which bear them up. If anything does happen to destroy the equilibrium of any portion of the snow, sometimes, it is said, if there is only so much commotion of the air as is caused by a shout, or even by persons speaking in the neighbourhood, that portion slips down, and, disturbing the snow beneath, displaces it also. The avalanche thus gathers volume and impetus as it advances, and if not soon checked by meeting some obstacle which it cannot overcome, may attain such a size as to be able to overwhelm an entire village, while the mere violence of the wind set in motion by its onrush causes the loose snow all round to be whirled aloft in dense clouds, and is sometimes sufficient to uproot trees on both sides of its path. One case is recorded in which the wind-gust of an avalanche overturned sheds on the opposite side of a river to that on which the avalanche occurred; and on another occasion the spire of the convent of Dissentis, in the Grisons, is said to have been thrown down by the gust of an avalanche which fell a quarter of a mile off.

The other kind of avalanche, the Rutschlawine or gliding avalanche, called in French the *avalanche du fond*, is apt to take place in spring or summer when the snow is melting. It generally occurs at the head of a valley when the water

running from the melting snow has, so to speak, lubricated the slope on which the snow rests. The snow then begins to slide down the valley in a compact mass, increasing, like the dust avalanche, in volume and rapidity of movement as it advances, but always remaining compact and firmly coherent. Though an avalanche of this kind never sweeps over so large an extent of ground as a dust avalanche may, the shock with which it strikes is necessarily greater. But probably the greatest danger attending this kind of avalanche lies in its tendency to block up the beds of streams and cause wide-spread inundations.

The best defence against avalanches is found in forests growing on the mountain sides in such positions as to check their career before they are fully formed. Forests so situated are placed in Switzerland, and other parts where avalanches are liable to occur, under the protection of the State, and the heedless destruction of such forests has in certain cases led to the depopulation of considerable districts.

We may mention yet another way in which snow may act destructively. This is by giving rise to what are known as *ice-storms* in forests. When snow falls in forests, and especially in forests of coniferous trees, such as are most abundant in those regions where snow falls most plentifully, the branches of these evergreens become laden with a heavy weight of snow, which they may bear until the snow has been converted by partial melting and subsequent re-freezing into solid lumps of ice. These present a still greater surface for the reception of fresh snow, which may be converted into ice in its turn. Sometimes

these accumulations attain such a weight that the branches can no longer support them. The topmost, weakest branches give way and fall down with the lumps of ice that they carry. These, acquiring impetus as they fall, strike against the lower branches and break them off. Thus the process of destruction is accelerated. The agitation is communicated to the contiguous trees, and from these to others, and thus in a brief space of time large areas in a forest may be in great part destroyed.

Snow is not to be seen in all parts of the world. Most people have heard of the Eastern monarch who refused to believe in the possibility of the existence of water in a solid form. Experience had not enabled him even to conceive such a thing. And there are many parts of the world where one might have to travel very far before obtaining ocular evidence of the way in which water might be converted from a liquid to a solid, and from a solid again into a liquid.

Snow is indeed to be found in all latitudes, for all latitudes contain mountains high enough to receive coverings of snow. But at sea-level snow never falls within a certain distance of the equator. This distance is greater in the southern hemisphere than in the northern, for in the former the predominance of water preserves a more equable temperature in the comparatively small areas of land. In that hemisphere snow is said never to fall at sea-level at a lower latitude than 48° S., while in the northern hemisphere the limit of snow at sea-level falls in some places as low as 30° N. This limit includes the whole of Europe, but in the extreme south of that continent,

snow, though it does fall at times at sea-level, does so very rarely indeed. The average number of snowy days in the year increases from the south northwards and from the west eastwards. At Rome, in lat. 41° 54′ N., lon. 12° 29′ E., the average is a day and a half in the year, at St. Petersburg, in lat. 59° 56′ N., lon. 30° 19′ E., 171 days.

But in all latitudes snow may be seen at all times of the year wherever there are mountains sufficiently high. In all such mountains there is a line on which snow is always to be seen on the part of the slopes immediately above and generally reaching to the mountain top. This line is called the *limit of perpetual snow*, or more shortly the *snow-line*, and varies in height with the latitude, the exposure, and the average amount of the snow-fall, as well as with other transitory conditions, such as the temperature of a succession of seasons.

The term "perpetual snow" should not lead any one to suppose that there is any elevation at which snow, after falling remains absolutely unchanged. All the snow that falls on the mountains, however high, is destined to disappear in course of time. It may gradually be forced down by the weight of new accumulations to levels at which it melts and runs away as water; it may be blown down to lower and warmer levels, and in this way great quantities of snow are removed by every high wind on snow-clad mountains; it may be melted by the heat of the sun far above the snow-line, or it may evaporate or disappear insensibly in the form of invisible vapour. We are apt to think of the process of evaporation as one that goes on only when there is considerable heat, because it is most rapid and

perceptible at high temperatures. But it is in reality a process that may go on even at freezing temperatures, and

FIG. 4.—MONT BLANC AND ITS ATTENDANT MOUNTAINS, WITH THEIR COVERING OF PERPETUAL SNOW.

the rate at which it does so depends not only on the temperature but also on the dryness of the air. Now on very

high mountains and in high latitudes the air is often very dry, and hence it sometimes happens that, even when the temperature does not admit of the melting of the snow, the amount present may be diminished with wonderful rapidity by evaporation. In such circumstances the toundras or plains of Northern Russia and Siberia have been known to be divested of snow in certain parts while the winter still prevailed. Still more striking proofs of the possibility of evaporation during the prevalence of freezing temperatures are furnished by Hayes, the Arctic navigator, author of "The Open Polar Sea." He records that clothes, after being washed, were hung up wet in the open air in the coldest weather. Naturally they at once froze into stiff lumps, but in a few days they were found to be quite dry and soft. Similarly he observed that slabs of ice, in spite of severe cold, gradually shrank in size, and ultimately disappeared.

It is not, then, because the snow that falls on the tops of mountains remains always the same that there is a limit of perpetual snow on the highest mountains even in the tropics. But this limit is that at which snow never altogether disappears before fresh snow has fallen to take its place. It is for that reason that it is not temperature alone that determines the height of the snow-line.

That temperature is a very important factor in determining the height of that line is obvious, and hence it follows that as a rule the snow-line is higher the nearer the mountains are to the equator. On the south side of Mont Blanc, in the Alps, the limit of perpetual snow is about 9,000 feet above sea-level, while on the Andes, near the

equator, it is situated at about the height of 16,000 feet—higher than the highest summit of the Alps. For the same reason the snow-line is usually higher on the side of a mountain exposed to the sun than on the side turned away from it. It is, for example, about 1,000 feet higher on the south than on the north side of the Alps.

But to this last rule it has long been known that there is a very important exception in the case of the Himalayas, an exception that proves that there is another important factor, besides temperature, affecting the height of the snow-line. Since the time of Humboldt attention has frequently been drawn to the fact that in those mountains the snow-line is higher on the north or colder side than on the southern, and therefore warmer slopes. The amount of the difference has been variously estimated by various observers, but there appears to be no doubt of the fact that the relative difference is as stated, not the reverse.

And it is not difficult to understand why it should be so. The southern slopes, though the warmer, are exposed to the moisture-laden monsoons which blow from the south during half the year in India, and at a certain elevation this moisture is precipitated in the form of snow. The northern slopes, on the other hand, are swept only by the comparatively dry winds that have crossed the interior of Asia, and hence the accumulations of snow in the course of the year are immensely greater on the south side than on the north. On the former side the power of the sun, on the Himalayas, just as on the Alps, is greater in causing the snow to disappear, but as there is much more snow on that side to be removed in the intervals between the

deposition of fresh snow, the line up to which its total disappearance can be effected is lower there than on the north.

The influence of the same cause in affecting the height of the snow-line is observable also in other cases. Before leaving Central Asia, we may note that on the Karakorum mountains, the next range to the north of the Western Himalayas, the snow-line is higher than on the corresponding slopes of the latter mountains, though as we pass still further north, to the Kuen-lun, Thian-Shan, and Altai ranges, in succession, we find that the snow-line descends the nearer we approach the poles, in accordance with the general rule.

Turning now to South America, we there meet with another striking illustration of the connection between the height of the snow-line and the amount of moisture in the atmosphere. On the southern parts of the Andes, Darwin was at first greatly astonished at observing the immense difference in the height of the snow-line within a comparatively small interval of latitude. In Central Chili, in about lat. 33° S., he found the snow-line at from 14,500 to 15,000 feet above sea-level, while only 9° further south, behind the island of Chiloe, he found it to descend to about 6,000 feet. But the explanation of this phenomenon, which he describes as "truly wonderful," he finds in the contrasting states of the atmosphere where this difference is observed. "The land from the southward of Chiloe to near Concepcion (lat. 37°), is hidden by one dense forest dripping with moisture . . . In Central Chili, on the other hand, a little northward of Concepcion, the sky is generally clear, rain does not fall for the seven

summer months . . . No doubt the plane of perpetual snow undergoes the above remarkable flexure of 9,000 feet, unparalleled in other parts of the world, not far from the latitude of Concepcion, where the land ceases to be covered with forest-trees; for trees in South America indicate a rainy climate, and rain, a clouded sky, and little heat in summer."—Darwin's "Journal of Researches."

The last words of the passage just quoted remind us that, even where temperature is the principal factor in determining the height of the snow-line, it is not the mean temperature of the whole year, but the temperature of the summer months, and indeed above all that of the hottest month of the year. For when the summer is sufficiently hot it will melt away all the snow, however great the accumulations may be. It is in this way that the difference in the height of the snow-line in Iceland between lat. 60° and 62° N., and in Norway between the same degrees of latitude is to be explained. The mean temperature of the year for the two places is about the same, but in Iceland the temperature is more equable, while in Norway there is a colder winter and a warmer summer. The result is that the cold summer of Iceland allows the limit of perpetual snow to descend to about 3,000 feet, while in the corresponding latitude of Norway it falls no lower than 5,500 feet. Hence, too, we find that the vicinity of the sea, while tending to produce a more equable climate, tends also to lower the snow-line on the mountains, so that, for example, that limit on the Pyrenees is about 2,500 feet lower than in the Caucasus, and upwards of 3,000 feet lower than on the northern slopes of the Thian Shan moun-

tains, though all these ranges lie in nearly the same latitudes.

But seeing that there are so many varying factors affecting the height of the snow-line, it need not excite surprise that even on the same slopes that line is a varying one. The limit of *perpetual* snow, even with the explanation above given of the term, is strictly speaking a false designation. During one summer the line up to which the snow melts may be found to lie at one elevation, while if the next summer is much hotter, or if a comparatively snowless winter has intervened, the snow will melt to a higher elevation, and that will be the upper limit of snow for that year. That is one reason why the limits assigned for perpetual snow by different observers vary so much, though in many cases the observers affect to fix it with great precision.

To determine a really permanent limit of snow it would be necessary to take a long series of years, and to ascertain the highest elevation to which it has melted throughout the whole period. And even then it would be only a relative permanence that was ascertained, for in rare cases it is found that the cap may disappear altogether even from very high mountains. Thus Darwin was assured that during one long and dry summer all the snow vanished from Aconcagua, a peak of the Andes that attains the height of more than 22,000 feet. The snow is said to have frequently disappeared from the Pyrenees. From the Jungfrau, one of the highest summits of the Alps, it all disappeared in 1842; from the Strahlhorn, in the same range, in 1860-62; and from Chaberton in 1859.

We may conclude our consideration of the subject of snow with a few words on the forms of life attached to this unlikely *habitat*. We do not here refer to the larger forms frequenting snowy regions, such as the polar bear and others already spoken of, but to the minute forms of vegetable and animal life found on the surface of snow. The best known and by far the most abundant of these is what is familiarly known as "red snow," a microscopic plant consisting of a single cell, which, when present, occurs in such inconceivably large numbers as to give a colour to the snow over which it is spread. It has been found in the Arctic regions of Europe and America, on the high Alps, the Pyrenees, and the Carpathians, and was seen also by Darwin on the Chilian Andes. It was known even to Aristotle, who probably saw it on the mountains of Macedonia, but it was not till comparatively recent times that its true nature was discovered. By men of science it has had various names conferred upon it. Most commonly it is known as *Protococcus nivalis*, but more recently this name has been changed for that of *Sphærella nivalis*. Besides this red snow a green snow has been observed in Spitzbergen, also due to the presence of a minute vegetable form, and as many as thirty-seven species have been enumerated as belonging to the flora of the Arctic snows, and this flora is accompanied by a fauna equally minute.

DRAGON-FLIES.

By W. S. Dallas, F.L.S.

If we are to believe the tales that have come down to us from early days, there were dragons in those times of a most formidable character. Breathing fire from their mouths and nostrils, cased in almost impenetrable armour, furnished with ample wings, and endowed with an insatiable appetite, their presence in any locality was, as we all know, a public misfortune; the people and their cattle were remorselessly consumed, and the monsters generally insisted upon having the tenderest of the young maidens served to them for breakfast.

Terrible as were these creatures, whose very breath was so pernicious, that to approach them incautiously was certain death, yet champions were found in all ages willing to attack them for some such trifling consideration as the hand of a princess; and it is somewhat remarkable, considering the nature of their antagonists, that from the time of Perseus to that of St. George, or later, these heroes generally managed in the end to be victorious in their combats. The knights-errant killed a dragon now and then, by way of a little change from their regular business of destroying the equally objectionable giants of those days, and they seem to have performed their self-imposed duties so thoroughly that both breeds are now extinct. The giants of our day will bear no com-

parison with the truculent monsters of former times; they are peaceful creatures contented with the same victuals as ordinary people, and show the entire absence of malevolence in their characters by travelling quietly from place to place and exhibiting their bulky forms to the admiring gaze of the public for a small price; while absolutely the only really formidable dragon that we can point to is the one at Temple Bar, which makes a show of fulfilling at least one of the traditional duties of its precursors in defending the treasures in Messrs. Child's bank, while it may perhaps serve a useful purpose by frightening people away from the dangerous vicinity of the New Law Courts.

But if the original dragons are extinct, their traditional peculiarities survive in the memory of men, and their name has been applied, not inappropriately, as we shall see, to certain well-known insects which are as formidable to their weaker fellows, as even the old-world dragons could have been to the inhabitants of the districts in which they took up their abode. Sweeping through the air upon powerful wings, and provided with a most formidable mouth-apparatus, the dragon-flies, as we call them in England, are the tyrants of the flying insects, which they snap up in their rapid flight, and then, alighting on some leaf or twig, mercilessly devour.

Curiously enough, our French and German neighbours, probably in gallant allusion to the elegance of form and grace of movement displayed by many of the species, have given these fierce creatures much more complimentary names, the former calling them "Demoiselles," or "young ladies," and the latter, perhaps in imitation of those

patterns of politeness, naming them "Wasserjungfern," or "water-maidens." The ideas involved in the English and French names are certainly "wide as the poles asunder," *young* ladies at any rate are not commonly designated dragons, whatever may be the case with their mammas; and if we consider the habits and manners of the insects, such a comparison as is implied in calling them *Demoiselles*, must be confessed to be not very complimentary to "the fairer part of the creation." The learned German entomologist, Dr. Taschenberg, admits this, and says:—"The Englishman, ever practical, has given them the most characteristic name," an opinion in which all Englishmen will coincide. In Sweden they are called "Trollsländer," which may probably be translated "goblin-insects," and is no doubt conferred upon them in allusion to the terrible mask formed by the external parts of the mouth; but notwithstanding the opposite example of many eminent scientific authorities who are always ready to introduce foreign terms into their writings, we shall not adopt the Swedish name. Another common English name for these insects, namely, "Horse-stingers," may also be rejected, seeing that they neither sting horses nor anything else; while another recorded name, that of "Devil's darning-needles," which is said to prevail in some parts of the country, must share the same fate, if only on account of the number of assumptions which it implies.

But whatever name we give them, whether we call them dragon-flies or damsel-flies (after the example of Thomas Moore) or goblin-flies, or adopt one of their scientific designations, such as *Odonata* or *Libellulidæ*,

the insects in question must be regarded as forming one of the best defined groups in their class; while at the same time the elegance of form and exquisite beauty of colouring exhibited by many of the species, their peculiarities of structure and habits, and the curious history of their development, render them particularly interesting. They are also so abundantly represented in most districts, and

FIG. 1.—LIBELLULA DEPRESSA.

such striking objects when on the wing, that the difficulty is for any one possessing eyes not to notice them, so that they may serve admirably to introduce the reader to some knowledge of the world of insects.

If we examine a dragon-fly, no matter of what species (see Fig. 1), the first thing that strikes us is that it consists of three distinct parts—in front, a rather large head; immediately behind this a thick, more or less humped division which bears two pairs of beautifully netted wings upon its hinder half; and, thirdly, a long and usually slender portion,

which is flexible, in consequence of its being composed of a series of divisions, or *segments*, as they are called, placed one behind the other. This division of the body into three parts—namely, the head, the thorax, or chest, and the abdomen—is one of the regular characteristics of the class of insects, of which the dragon-flies are conspicuous members; just as its being composed of numerous joints or segments, such as we recognise at once in the hindmost division of the dragon-fly, is a leading external character of the still larger group of "jointed-limbed animals" (*Arthropoda*), which includes the insects, spiders, crabs, lobsters, shrimps, and many other creatures.

These are important points in general zoology that we may learn from even a superficial examination of a dragon-fly, but in order to understand the structure of the insect we must go a little more into details. To commence with the head, this is generally of a nearly hemispherical form, but sometimes much widened, and set on the front of the body something like the head of a hammer upon its handle; it is much hollowed out behind so as to fit over the front part of the thorax, to which it is attached by a very slender neck, so slender, in fact, that one almost wonders to see that there is so little room for the passage of the food considering the voracity of the insect. When the head is hemispherical its upper surface is almost entirely occupied by a great pair of eyes, often beautifully coloured, which meet in the middle line; these are of the kind called "compound eyes," which occur in most insects, and consist of a multitude of distinct organs of vision, each furnished with a separate lens, the junction of which divides up the surface of

the organ into an immense number of "facets" as they are called. These are sometimes all of the same size, sometimes those of the upper part of the eye are larger than those of the lower part; they are so numerous that in some species each eye is estimated to contain about twelve thousand of them. In the wide-headed species the eyes are smaller and separated by a considerable portion of head; but they are then nearly globular, and from their greater prominence have perhaps even a wider range of vision than in the other forms.

When the eyes meet in the middle of the head, the crown is reduced to a small triangular piece at the back of the head and a convex portion in front, which latter is separated by a groove from the actual face of the insect; and, as though the extraordinary apparatus of eyes already mentioned were not sufficient for the wants of the creature, we find in this groove three simple eyes, of which the middle one is often larger than the others. These simple eyes (or *ocelli*) are little convex glassy lenses, and they probably serve some purposes of vision for which the great compound eyes are not adapted.

In most insects the front of the head bears a pair of long jointed organs commonly called "feelers" (by entomologists *antennæ*), the function of which must be regarded as doubtful. In the dragon-flies these organs are very small, perhaps smaller in proportion than in any other insects; they are placed in the groove near the side simple eyes, and resemble short bristles, having two slightly-thickened joints, followed by a tapering thread-like part composed of five or six joints.

Below the groove with its simple eyes and antennæ comes the broad and usually prominent face, which combines with the outer organs of the mouth to make a mask which, if larger, would be as frightful in its aspect as even the head of the fabled creature from which the insect takes its name. These outer parts are the upper and lower lips, within which the actual masticating organs are concealed. "In a dead dragon-fly," says Mr. McLachlan, "the parts are closed together, and, for a just appreciation of their structure and power, it is necessary to take a living example in the fingers by the thorax, slight lateral pressure on which causes the insect to display this formidable arrangement." The upper lip (*labrum*) although large, shows no special peculiarities, but the lower lip (*labium*) which, as in all insects, is a jointed organ, has a very remarkable though variable structure. It is of considerable size, and bears two large side-pieces, supposed to represent the jointed appendages of the lower lip in other insects; these, when the mouth is closed, assist in concealing the inner organs, but they can be opened and separated, when each of them is found to have at its extremity a little spine-like joint, which is of material assistance in holding the prey while it is being torn and devoured by the action of the jaws. Of the latter organs, as in insects generally, there are two pairs, a pair of strong, horny *mandibles* formidably armed with several sharp points at the extremity, and a pair of jointed jaws (*maxillæ*), the tips of which are also sharply toothed. These jaws are not visible externally when the mouth is closed.

The second division of the body, the thorax, or chest, is

composed in insects of three segments, but these are not so easily recognised in dragon-flies as in some other insects. The first segment, however, is plainly marked, but it is of very small size, forming merely a narrow collar in front of the thorax, continued forward into the narrow neck which bears the head. Owing to this slender attachment the head can be turned in all directions with wonderful facility, a power which is doubtless of the greatest service to the animal in its predatory mode of life. The other two segments of the thorax are united into a mass, but their original separation is still marked by an irregular line which runs slanting forward down each side of the thorax. The great robustness of the thorax is explained by its having to give support and lodgment to the strong muscles by which the large and powerful wings are worked, these organs being attached in two pairs to the hinder upper surface of the two large thoracic segments. These wings, the two pairs of which are nearly of the same size, although slightly differing in shape, are generally membranous and more or less transparent, and they are traversed by a most complicated network of delicate horny veins which serve to stiffen and support them. It will be unnecessary for our present purpose to consider the details of this beautiful veining, further than to say that the strongest and principal veins may be observed to run through the length of each wing near its fore margin, while the hinder and more flexible parts of the wing show chiefly an elegant network of more delicate veins forming pentagonal and hexagonal meshes. At the lower part the thorax has three pairs of rather long, bristly, but not very powerful legs, each termi-

nated by a foot (*tarsus*) composed of only three joints, the last of which bears a pair of slender claws. Owing to the arrangement of the segments of the thorax the whole three pairs of legs are thrown forward in front of the attachment of the wings more than in any other insects; in fact, it is quite clearly to be seen that in the general economy of the dragon-fly the wings are the most important external organs; its organisation is adapted to an existence on the wing, but at the same time the slender and comparatively feeble legs serve admirably to enable the creature to alight gently upon the leaves or twigs on which it reposes after its aërial excursions, and while engaged in devouring its victims, and to rise from them again with the greatest ease on the approach of danger or of a desirable prey.

We have now only to consider the structure of the abdomen, or third division of the body of our dragon-fly, and this need not detain us very long at present. This part is generally slender and cylindrical, but sometimes prism-shaped, that is to say, if cut across it would show a triangular form; in some of the species which show this peculiarity it is much stouter than in the generality of the group. In the abdomen we can count ten segments, the first of which is exceedingly short, while the tenth in both sexes is furnished with external appendages of various forms.

Although the European and even the British species of these striking insects are of very respectable dimensions, it is in the warmer and, indeed, in the tropical regions of the earth's surface that the group has its true home. Thus Mr. McLachlan, in his valuable article in the "Encyclo-

pædia Britannica," estimates the total number of known dragon-flies at about 1,700, of which only about 100 occur in Europe, and of these 46, or nearly one-half, are to be met with in the British Isles, and we possess common representatives of all the principal forms, so that, although for the very largest and the most remarkable species of all we must go to the tropical regions of America and the East, the British entomologist has no occasion to travel beyond the boundaries of his native country to obtain a good knowledge of the characteristic phenomena of Libellulan existence.

Like their tropical relatives our dragon-flies are lovers of the sun, and accordingly in temperate climates they must be regarded as essentially summer insects. In England they are to be seen from May until September, but chiefly in the two intermediate months of June and July. They usually haunt the neighbourhood of water, over the surface of which they may be observed flying by the hour together, so long as the sun shines brightly; dull, cloudy weather, however, renders them very sluggish and inert. Their preference for the neighbourhood of water is probably due to two circumstances: in the first place, their development, as we shall see hereafter, takes place within it; in the second, the profusion of gnats, midges, and other soft-bodied insects which, also having their birthplace in the water, pass their brief aërial life in hovering over its surface, ensures them an ample supply of suitable food. Some species, however, by no means confine themselves to watery localities, but may be met with sweeping along hedgerows and over the open fields and heaths. These,

however, are only excursions, probably in search of change of diet, for it must be remembered that for the purpose of depositing their eggs the females at any rate are obliged to visit the water, although a very small permanent accumulation of water will suffice for the development of the insects.

Among our British species of dragon-flies, one of the most abundant, the *Libellula depressa* of entomologists, furnishes an example of the wandering habits just mentioned, although it is also frequently to be seen about water. It is a stout and strongly-built insect, with a robust thorax, powerful wings, and a broad abdomen (see Fig. 1). It seems to be one of the species to which the popular name of "Horse-stingers" more properly applies. In length this insect is something less than two inches, while its wings, which are always extended nearly at right angles to the body, spread about three inches from tip to tip. Its general colour is a yellowish-brown, with rounded yellow spots on the sides of the segments of the abdomen; but in the mature male the upper surface of this region of the body is coloured light-blue by a powdery exudation resembling the bloom seen on many plums. The wings are transparent and reticulated with dark veins; towards the base the fore-wings have an oblong, and the hind wings a triangular brown patch, the veins in which are tawny; the legs are black with reddish thighs. A very similar species, the *Libellula quadrimaculata*, in which, however, the abdomen is more narrowly conical, is of a general dull red colour with the head yellowish, and the tip of the abdomen black or dark-brown, and some black lines on the sides of the thorax; the wings in this

species are also transparent with dark veins, but the base in both pairs is yellow, and there is a reddish-black spot on the fore margin in each wing, in addition to the triangular patch near the base of the hind wings, which is traversed by yellow veins. This species, which is about the same size as the preceding, is hardly so common in Britain. Both these species are in the habit of travelling far from their birthplace, not only in single individuals, but sometimes in great flights which seem to constitute veritable migrations. According to reliable observations the second of the above-mentioned species engages in these expeditions more frequently than the other. Dr. Hagen describes the passage of a swarm of *Libellula depressa* over Königsberg in June, 1852. The insects were so numerous that they formed a compact band sixty feet wide and about ten feet deep; they passed at about the speed of a horse in an easy trot, and the passage of the swarm continued from about nine in the morning until evening, and even then the last portions of the swarm took up their abode for the night in the suburbs of Königsberg, where they covered the houses and trees, and the next morning proceeded on their journey in the same direction as their predecessors. Dr. Hagen came to the conclusion that the insects observed by him had not long emerged from the pupa state, and thought that this circumstance would indicate that they had undertaken this remarkable journey in obedience to a migratory instinct, as they could not have had time to ascertain that there was any scarcity of food in their district. The Abbé Chappe, who visited Siberia in 1761 to observe the transit of Venus, records an observation

made by him at Tobolsk, of the passage of a swarm of the same species of dragon-fly, but he gives it the enormous breadth of five hundred ells and a length of five leagues! In some parts of North America similar migrations of *Libellula quadrimaculata* have been observed, and examples of the same and other species have come on board ships sailing on the open sea, in one recorded instance over six hundred miles from land.

Besides these and other more or less similar species, we have in Britain several in which the abdomen is much more slender, although still of a prismatic form. Some of them are tolerably abundant, the commonest and most generally distributed being *Libellula vulgata* and *L. sanguinea*, in both of which the males are of a reddish colour, while the females show rather an olive tinge. They have the wings semi-transparent, and the stigma, or little opaque patch near the tip of their fore margins, is brownish in the former, red in the latter: these insects are from an inch and a quarter to an inch and a half in length.

Besides these and other species with a more or less distinctly prismatic abdomen, there are a considerable number having, like them, the head hemispherical, the eyes in contact on the surface of the head, and the wings always extended, but in which the abdomen is cylindrical, although frequently thickened or clubbed at the end. Most of these are of large size, and possess great power of wing, which is aided, apparently, in enabling them to sweep about in pursuit of their prey by the steering action of the long and flexible abdomen. Accordingly,

Fig. 2.—ÆSCHNA MACULATISSIMA, WITH ITS FULL-GROWN LARVA AND PUPA.

these insects may be observed hawking about over the surface of the ponds and other waters in which they have been bred, now darting rapidly from place to place, or sweeping round and round in wide curves, and occasionally poising themselves in the air by a rapid vibration of the wings, especially when about to alight upon some leaf or twig, either to rest from their exertions, or to devour some choice victim more conveniently. When engaged in these aërial exercises these insects are by no means easy to capture, as they will persist often for a long time in circling about over the surface of the water, constantly sweeping past the expectant entomologist only just beyond the reach of his net, as if possessing a perfect consciousness of his kind intentions towards them, but at the same time taking a malignant pleasure in thwarting him.

Of these forms many are abundant in various parts of England. Most of these belong to the genus *Æschna*, two of which [*Æschna grandis* and *Æ. maculatissima* (see Fig. 2), large species not much less than three inches long], are abundant and widely distributed. The largest of the British species is the *Anax formosus*, which measures over three inches in length and as much as four inches in expanse of wing. As implied in its name this is a very beautiful insect, the colours in the male consisting of a mixture of azure-blue, green, and yellow, set off with various bands and streaks of black. The female is not so handsome. Some exotic species are larger, the greatest dimensions recorded being for one from Borneo, the wings of which spread about six and a half inches.

In *Gomphus vulgatissimus*, a not uncommon smaller species, measuring only an inch and three quarters in length, we find the outspread wings combined with a cylindrical abdomen and widely-separated eyes, thus leading us towards the second division of the group in which the head is so wide that the eyes are in a manner stalked. The simple eyes here are placed in a curved line upon the crown of the head. *Cordulia ænea* and its allies, in which the eyes are in contact in front, constitutes another link with the next group by having the surface of the body of a rich metallic tint, a peculiarity which occurs more or less distinctly in many of the broad-headed, slender-bodied species to which we have now to refer.

This second division of the dragon-flies is characterised by having the head much widened, with the globose eyes separate and very prominent, the simple eyes placed in a triangle on the crown, the abdomen slender and cylindrical, and the wings narrow and brought together over the abdomen when the insect is at rest. The group includes a considerable number of species, and amongst them are the most familiar of our native forms. The common blue and red species, which may be seen hovering over every pond and ditch, or resting lightly upon the surrounding twigs and herbage, are among the most ordinary objects observed during a summer stroll, while from their comparatively feeble flight they are much more easily captured than their fellows, to which we have hitherto devoted our attention.

The wings of these species are narrower and stretched by feebler veins than in the more robust forms, and

in the ordinary species the meshes of the network formed by these veins are quadrangular instead of pentagonal or hexagonal. The whole texture of the wing is more delicate, and in accordance with this character the motions of the insects in the air are often more fluttering than in the *Libellulæ* and *Æschnæ*. It is no doubt to these elegant and graceful creatures with their delicate gauzy wings that the French name of "Demoiselles" more particularly applies, and they are evidently the "beautiful blue damsel-flies" of "Lalla Rookh." Our ordinary "blue damsel-fly," which may be met with everywhere in the vicinity of water, the *Agriòn puella* (Fig. 3), is a delicate azure-blue species, variegated with brassy-black markings, in such a way that the thorax exhibits brassy and azure bands, while the segments of the abdomen above are bordered and marked with brassy-black so as to have a ringed appearance. The length of this species is about an inch and a third. The common red species (*Agrion minium*) is of about the same size, and is of a blood-red colour, with the upper part of the thorax brassy-black, and the segments of the abdomen margined behind with black.

Many of the exotic species of this group are of very much larger size than any of which these islands can boast, some tropical American forms having wings which spread about seven inches when extended, and an abdomen four or five inches long, although not thicker than a thin straw. Our largest species, *Calopteryx virgo* (Fig. 3), is not quite two inches long, and about two-and-a-half inches in expanse of wing. Its colour varies from

green to blue, but its surface always shows a silky or metallic lustre, and its wings are usually of a deep metallic blue-black with only the base and the extreme tip pale or translucent. When on the wing, hovering over its native pond or river, this is a most elegant creature, and its strongly-coloured wings and general metallic lustre distinguish it at once from all our other British species. Among exotic forms, however, opaque wings of a more or less metallic aspect are not wanting, and in some cases they are exceedingly brilliant; in one curious instance of a small form from South America, while the fore-wings are transparent, the hind ones are "of the most brilliant, fiery, metallic colour," rendering it, as Mr. McLachlan says, "a gem in the world of insects."

The foregoing statements will, we trust, have given the reader some idea of the characters and general habits of the group of dragon-flies, and also of the leading characteristics of the various forms presented by those insects. We have still, however, a few words to say as to their reproduction and development.

After the pairing of the insects the female deposits her eggs in the water, sometimes attaching them in masses to the stems of aquatic plants, sometimes merely touching the surface of the water with the extremity of her abdomen, and dropping the eggs singly into it; and sometimes, according to Professor Siebold and others, creeping down the stems of water-plants several inches below the surface, where she deposits her eggs. In the case of one of these slender species (*Lestis sponssa*), Siebold

FIG. 3.—CALOPTERYX VIRGO AND AGRION PUELLA.

observed that the male continued his hold upon his partner and accompanied her in this sub-aquatic expedition; he saw two pairs engaged in depositing their eggs upon the stem of the same plant. In this, and perhaps in some

other species, the female inserts her eggs in small incisions which she makes in the tissues of the plants by means of a sort of serrated ovipositor with which she is provided.

Probably nearly every one is aware that the young progeny of most insects make their first appearance in the world under an aspect somewhat different from that of their parents. In many cases, indeed, there is no resemblance at all between the parents and their offspring, as with the caterpillars of moths and butterflies, the grubs of beetles, bees, and wasps, and the maggots of flies; and in these instances the development is not direct, but there is a peculiar resting-stage in which the insect does not move or feed immediately before it assumes the likeness of its parents; while in others a certain similarity may be recognised from the first, the chief differences consisting in the smaller size of the young animal and its entire want of wings. This latter mode of development, known as "incomplete metamorphosis," is that which occurs in the dragon-flies; the young insect (or *larva*) has a rude general resemblance in its external characters to its parents, although it is specially adapted for an aquatic mode of life, and its development into a perfect dragon-fly takes place by a series of gradual changes brought about by successive moultings, without any resting period whatever. In the later stages of this process the wings are gradually formed and enlarged under the skin, but they do not attain their full size and mature characters until after the creature has emerged from its last preparatory skin.

The young larvæ of the dragon-flies certainly present a rather imperfect likeness to their parents; still, the same parts are recognisable, and there is even a rough similarity in general form. Thus, the preparatory stages of the *Libellulæ* are broad and stout, while those of the robust forms with cylindrical bodies are more elongated, although still of the same shape, and, in both, the eyes, as in the perfect insects, are flush with the surface of the head; but in the slender-bodied species with projecting eyes, these same forms are reproduced in the larvæ and pupæ. The habits of all these young states are very similar; they live at the bottom of the water and prey voraciously upon their weaker companions, for carrying out which tyranny they are particularly fitted by a peculiar arrangement of the lower lip. This organ in the larvæ and pupæ of the dragon-flies is composed of the same parts as in the perfect insects, but these are lengthened out in a remarkable manner, and arranged so as to be folded beneath the head, forming a sort of flattened mask of most innocent appearance, from which no notion of its formidable nature could be gathered. When unfolded the base of this labium or lower lip is found to consist of a greatly elongated chin-piece, which is articulated to the hinder part of the lower surface of the head by a sort of hinge-joint, and has, attached by a similar joint to its slightly widened extremity, a second piece, which becomes still more dilated, and forms the chief part of the mask produced when the apparatus is contracted. This represents the true lower lip. At its extremity again, we find articulated a pair of pieces, representing the side-pieces which, in the perfect

insects, assist in closing the aperture of the mouth, and also in holding the prey, and are regarded by many entomologists as representing the feelers or palpi of the lower lip. This is, in general terms, the construction of this remarkable mask, which is varied in the different groups more or less in accordance with the structure of the corresponding part in the perfect insect, while at the same time the mode of action and the functions of the organ remain the same in all.

In a state of repose the long chin-piece—which, as above stated, is hinged to the hinder part of the lower surface of the head—is folded back, so that it lies packed away between the bases of the first pair of legs. The second broad and dilated piece, which is hinged on to its extremity, is then folded forward, and laid closely upon the whole front of the head, which it thus seems to cover in with a great horny plate, at the upper part of which are situated the two side-pieces also carefully folded in. But all these parts can be extended, and when extended it will be seen that the forceps-like extremity of the whole organ will be thrown forward considerably in advance of the head (Fig. 4). Thus the chin-piece is so long that, when thrown forward, its extremity reaches in front of the foremost part of the head; then the next division of the organ, being as long as the chin-piece and head together, reaches more than its own length in advance of the head, carrying with it the two side-pieces which form a powerful grasping organ, capable of seizing and at once carrying back within reach of the jaws any small feeble organisms against which they are directed. In fact, this curious arrangement is precisely

analogous to the construction of the tongue in the chameleons and especially in the frogs; in all three groups the insects and worms which constitute the diet of the animals, are secured by the sudden darting forth of a prehensile organ—the tongue in the vertebrates and the lower lip in the insects. Armed with this formidable apparatus, the dragon-fly larva, which is a sluggish, dingy creature, is enabled to get a very good living at the bottom of the water in which it dwells; crawling slowly along, there is nothing in its appearance or movements to call attention to its presence, but the moment it comes within reach of a suitable prey, or a desirable victim passes near to it, the lower lip is darted out to seize it.

FIG. 4.—PUPA OF DRAGON-FLY, WITH LOWER LIP EXTENDED, SEIZING ITS PREY.

There is another matter connected with the aquatic life of these larvæ to which we must advert. We have seen in what manner they obtain their food, but for the carrying on of the vital processes there is another necessity equally pressing, namely that of respiration. In insects, as we all know, this function is not performed by means of lungs or other organs into which the blood is driven for the

purpose of being brought into contact with the air, but the whole body is pervaded by a system of delicate tubes, into which air penetrates, and is thus brought into contact with the circulating fluid at all points. The dragon-fly larvæ, although living constantly in the water, still have their respiration performed by the agency of these air-tubes, although they do not, like many other aquatic larvæ and all insects which inhabit the water in a perfect state, come from time to time to the surface in order to take in a fresh supply of air. The mechanism by which their respiration is effected is curious and interesting.

In most water-breathing animals, as is well known, the blood is either exposed to the influence of the air contained in the water through the general integument of the animal, or driven into specially modified portions of integument forming what are called branchiæ, or gills. But in the dragon-flies and some other aquatic larvæ, the air is separated from the water and passed into the breathing tubes (*tracheæ*) which here, as in insects generally, convey it to all parts of the body. The precise mode in which this is effected differs in the larvæ belonging to the two divisions of the group which we have recognised.

The larvæ of the slender-bodied forms, with broad heads and the wings upright in repose, are themselves long and slender, and bear at the extremity of the abdomen three delicate leaf-like gill-plates through which fine branches of the breathing tubes are abundantly distributed; these take up the air from the water, and pass it into the tracheæ in the interior of the body. These gill-plates, which, besides their respiratory function, appear to act to some extent as

fins, enabling the larvæ to swim slowly through the water, differ considerably in length in different larvæ; they are largest in that of the beautiful *Calopteryx virgo* (Fig. 3), in which they are nearly as long as the whole abdomen.

In the larvæ of other forms of dragon-flies there are no external gill-plates, but respiration is effected in a cavity formed by the rectum, or the last portion of the intestinal canal, into which the water flows. The aperture leading into this cavity can be closed by an apparatus of five valves. The walls of the rectum are furnished with peculiar gill-plates and are strongly muscular; when the cavity dilates the water flows into it and thus comes in contact with the breathing apparatus; the muscles then contract, and the water, from which the air has been exhausted, is expelled through the aperture with considerable force. In fact, this expulsion is often so forcible that the insect is moved gently forward in the water by the effect of its recoil. This mode of advance is strictly in accordance with the stealthy habits of the creature: disguised under a thin coating of mud particles, it moves slowly and almost imperceptibly along, sometimes crawling by the agency of its six legs, sometimes floating rather than swimming by the expulsion of water from its respiratory cavity, or by the slow waving of its gill-plates which act as a sort of caudal fin, until it comes within easy reach of its intended prey, when the formidable prehensile apparatus of the lower lip is at once shot forward, and the struggling victim is secured.

The duration of the existence of the dragon-flies in their preparatory states varies considerably in the different

species. In the case of the smaller forms, such as the common blue and red slender-bodied dragon-flies, it probably lasts less than a year, that is to say, the larvæ hatched from eggs deposited in one summer produce the dragon-flies in the next. The occurrence of more than one brood in the year in some of these species has been suggested, but considering the short period during which the insects appear in the perfect state, this would seem very improbable. The larger and more robust species are known to occupy more than one year in completing their growth; some are known to pass three years in their preparatory stages, and this may probably be taken as the rule for all the largest species.

Of course, as in the case of all insects, the gradual increase of size is accompanied by successive changes of skin. It is not known, however, how often this process takes place in the course of the development of the larvæ, the number of moults will probably increase in proportion to the duration of the preparatory stages, so that in the large species which pass three years in their development, they will be very numerous. There is no resting pupa stage, such as occurs in beetles and butterflies, but only a gradual and continuous development, during which the creature moves about and feeds; but at a certain period the rudiments of wings make their appearance enclosed in cases on the back of the thorax, and then the insect is regarded as having entered upon the pupa, or, as it is called, the *nymph* stage of its existence. This appearance of wing-cases takes place at the second or third change of skin before the last; and at each subsequent moult the

sheaths and the enclosed wings increase in size, until immediately before the emergence of the perfect dragon-fly, they may cover about half the upper surface of the abdomen.

All these changes take place under water, but previous to the final and most striking transformation, the insect quits its former habitation and creeps up into the air, of which it is in future to be a denizen. For the purpose of this last change the nymph usually selects the stem of some plant or tree growing out of the water or immediately upon its brink, and laboriously ascends this to a suitable position, often several feet above the surface of the water. Here it clings firmly by means of the claws with which its feet are terminated, and awaits the further process of its liberation. This commences by the bursting of the old skin along the back of the thorax, and through the slit thus formed the insect, by a series of strong efforts, sets free its head and thorax, with a part of the abdomen, together with the legs and still rudimentary wings, which have to be pulled forcibly out of their respective sheaths. Through all these and the subsequent operations the old skin continues to cling firmly by its claws to the original point of support; the hinder portion of the abdomen still remains within its encasement, while the fore part of the body, apparently exhausted by the efforts necessary for its liberation, hangs down outside the case in a most helpless fashion (Fig. 5). During this period of repose, however, the various parts of the new-born dragon-fly are acquiring their mature form, size, and vigour, and after a time the head and thorax are raised until the insect

can cling with its feet to the empty fore part of the skin, or to the solid support of the latter. Then, by a fresh effort, it gently draws forth the remainder of the abdomen, and stands a perfect dragon-fly, although with very small wings, upon the outside of the case from which it has just emerged.* The completion of the development is effected by the gradual extension of the wings, and then, after resting for a time to dry and harden, the perfect insect dashes off to resume in a new sphere its life of rapine, and in due time to provide for the continuance of its race. How long it continues to live after its final transformation is not precisely known, but under certain circumstances its life may extend to several weeks, during

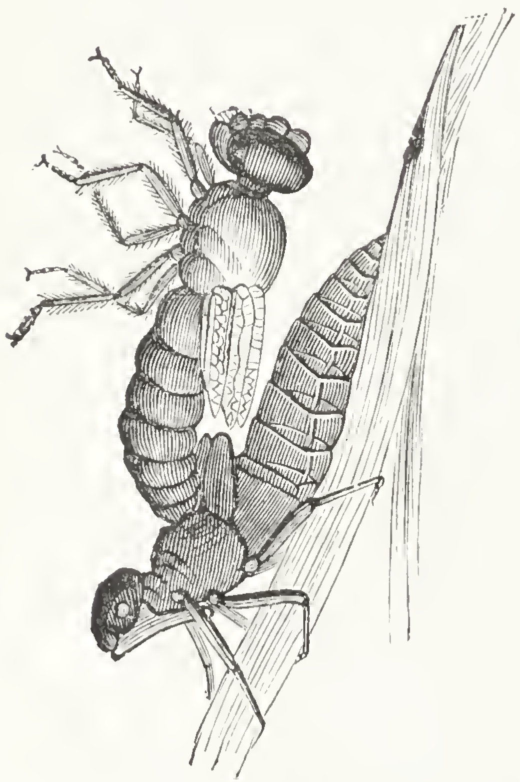

FIG. 5.—DRAGON-FLY EMERGING FROM THE PUPA.

* "To-day I saw the Dragon-Fly
Come from the cells where he did lie;

An inward impulse rent the veil
Of his old husk; from head to tail
Came out clear plates of sapphire mail.

He dried his wings, like gauze they grew;
Through crofts and pastures, wet with dew,
A living flash of light he flew."

TENNYSON.

the whole of which it wages a perpetual war upon the weaker denizens of the air. In fact, throughout its whole existence every dragon-fly is engaged incessantly in the destruction of other creatures, realising on a small scale—to revert to the point from which we started—the havoc made by the dragons of old, tyrannising in its younger states over the inhabitants of the water, after the fashion of the great sea-dragons of the Jurassic period, and, when fully developed, apparently trying to live up to the attributes of the legendary dragons of a later date. Unlike the latter, however, the influence of dragon-flies as regards mankind must be regarded as beneficent, seeing that in fulfilling their mission of keeping in check the inordinate increase of the smaller insects, they must destroy an infinite number of our insect plagues.

OAK-APPLES.

By F. Buchanan White, M.D., F.L.S.

Once upon a time—to use the familiar phrase with which all fairy tales begin, in that month which poets were wont to call the "merry month of May," a certain English monarch was obliged to hide himself from his enemies, and found a secure refuge amongst the umbrageous foliage of an oak-tree. It is possible that while perched aloft the king's attention may have been directed—if he was not too much occupied in thinking how he was to escape—to certain pretty fruit-like red and yellow balls with which the tree was studded. Be that as it may, after he did escape and had triumphed over his enemies, it became the fashion amongst his followers to commemorate the happy event by wearing in their hats on every succeeding 29th of May oak-apples gilded, as if Nature had not already decked them in bright enough colours. That fashion has long since vanished, but to this day every country schoolboy is reminded by the oak-apple of the day when Charles the Second hid in the Boscobel oak. We are not, however, concerned with the romance with which tradition has enveloped the oak-apple, but rather with the plain matter-of-fact questions, what is it? and what is its origin?

It is a primary injunction to the student of science that every object of his study must—if he wishes to *know* what it is—be subjected to observation and experiment. Let us

apply these to the oak-apple. The senses of sight and touch will show us that it is a more or less rounded body of perhaps an inch in diameter, fruit-like in appearance (as the common name implies), yellowish-green in colour, but usually red on one side, or even over a considerable part of the surface, and soft and velvety to the touch. We may also observe that it is attached to the branch (generally a small one) of an oak. It is fruit-like in appearance. Let us apply another sense—that of taste—to it, as many a child has doubtless done. Once will be enough; its bitterness does not tempt us to try that means of observation again. But the idea that it is a fruit may be dismissed at once, for we know that the fruit of an oak is a very different looking object, and that apples and acorns do not grow on the same tree.

We will now investigate the internal structure of our apple, and taking a knife, make a transverse section of it. We shall find that it is soft and juicy, and that towards the centre it contains a number of cavities, each surrounded by a more compact wall than the general texture, and each containing a small whitish grub, or maggot. Now, if we are hasty we will jump to the conclusion that just as the caterpillars in a real apple or other fruit have made their way in from the outside, so these maggots have entered into the oak-apple. If they have done so, surely there will be traces of the holes by which they entered, but we cannot find any. This (namely, how the maggots came to be in the oak-apples without leaving any indication of their mode of entry) was a problem that much exercised the minds of

some of the older writers on natural history, and many an ingenious theory was promulgated in fancied explanation thereof. Nowadays we smile when we read these, but it must not be forgotten that we start where our forefathers left off, and that we have many appliances to aid us in discovering the truth that they were without. We should also remember that we ourselves are quite as much in the dark with regard to the true nature of many common phenomena and functions of life, and that, very likely, some of the theories on which we now plume ourselves may seem fully as ridiculous to our successors as some of the theories of our predecessors seem to us.

Continuing our observations, let us examine the maggots themselves, and see what we can learn from them. They are minute creatures, but with the aid of a lens we can get a general idea of their structure and form, which is as follows: Body somewhat tapering to each end, divided into thirteen segments, or rings, of which the first is the head. No feet, but in the place of them indistinct tubercles, by which the animal moves to the limited extent that it has any necessity for. Mouth furnished with jaws, but rather rudimentary in structure. Along each side of the body a row of spiracles, or openings of the breathing-tubes. Integuments rather soft, and colour yellowish-white. From these characters we learn that the maggots are insects (Fig. 1), but which of the orders or divisions of insects they belong to further information is required to show.

This we may obtain by continuing our observations on the life history of the inmates of the oak-apples. But before doing so we must ascertain on what the maggots

feed. There is little difficulty in deciding that this must be the substance of the apple, for the very good reason that nothing else is accessible. If we choose to try more chemical experiments, we can ascertain that the substance of the apple is very rich in nutriment, much richer, in fact,

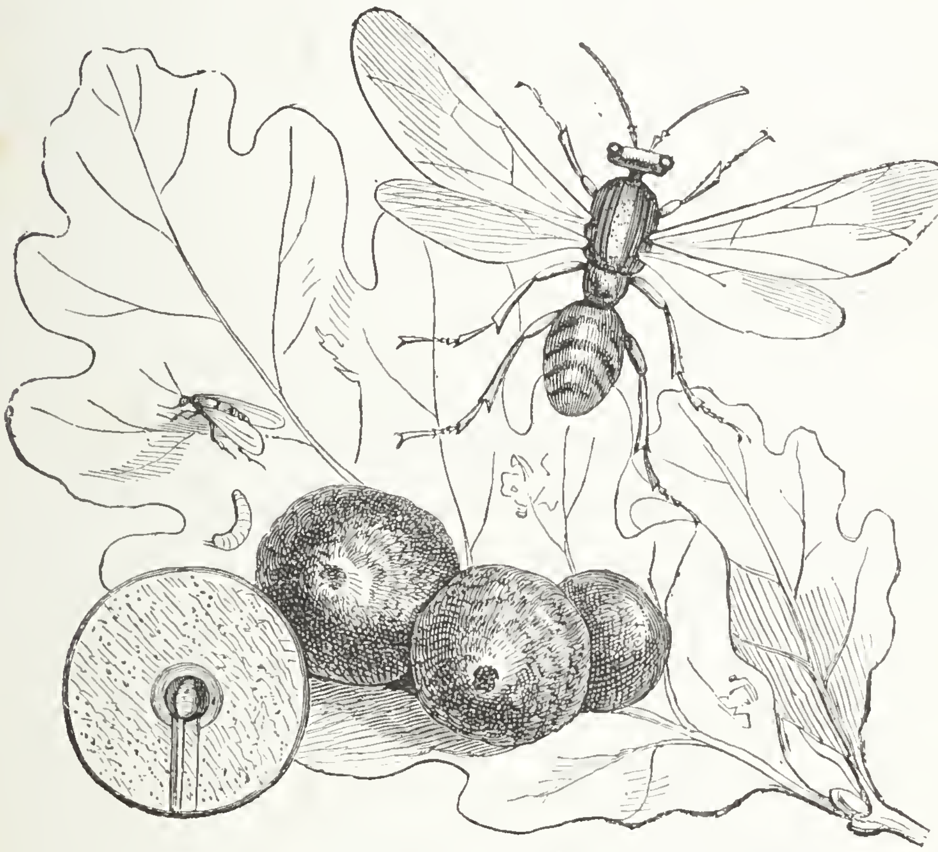

FIG. 1.—GALL INSECT.

than the leaves of the oak. A caterpillar that feeds on leaves has to eat a comparatively large quantity to obtain the necessary material for building its structure. The inmate of the oak-apple requires much less, and for several reasons. One is that the substance on which it feeds is rich in nitrogenous products; another is from its mode of life. When we wish to fatten an ox,

we give it abundance of the most nutritious food and keep it in a stall. In like manner Nature treats the oak-apple maggot, giving it abundance of nutritious food close to its mouth, so that it is not called upon to waste its strength by going in search of it, and a secure stall in which to dwell, where it not only enjoys an equable temperature, but *seems* to be protected from all external influences that may hurt. We say *seems* to be; we shall have occasion to see that even in the seclusion in which it dwells enemies may get at it.

No wonder, then, that in the course of a few weeks the maggot has got fat, and is ready to assume the next stage of its existence. This is what is called the pupa stage, and if we cut open an apple about this time we can see for ourselves what this is like. During the growth of the maggot, and as it increased in size, its skin became too small for it, so that it—like other maggots and caterpillars—found a change necessary. This it does by growing a new skin below the old one, and then casting the latter off. After doing this several times, and arriving at its full growth as a maggot, it changed its skin for the last time; but instead of appearing in the same form, it on this occasion assumed a different one, and became a pupa—the name by which the third stage in the growth of an insect is known. This pupa is of rather a different shape from the maggot, being thick at the head end and tapering towards the other extremity. It is now provided with legs, but these are not for use, each being packed into a separate sheath, or case, and neatly folded on the breast. In like manner the antennæ and rudiments of the wings

are packed away in separate sheaths, folded upon the case which enwraps the whole body. It has no mouth and little power of motion, and lies in the cavity in which it lived as a maggot, waiting for the time when its growth will be completed and it will become a perfect insect. The legs, antennæ, &c., that we see in the pupa are those of the perfect insect, and though the creature seems almost as if dead, yet inside of it growth is still going on, perfecting it for its future life. After being some days, or perhaps weeks, in this condition, the pupa is ready for its last change, and if we are fortunate, we may open an apple at the right time and observe the metamorphosis.

When the momentous instant has arrived the skin of the pupa bursts at the back, and the creature contained in it crawls out, pulling out its legs and antennæ from the sheaths which have contained them. At first it is moist and flabby, but soon its integuments dry and harden, its wings expand, and behold, we have a four-winged fly (Fig. 2). This fly would still have had to extricate itself from the prison in which it is confined, the cavity of the oak-apple in which the maggot lived, if we had not broken its prison walls for it, and this it would have done by gnawing a tunnel to the surface, for which purpose it is provided with stout jaws. In old oak-apples, which may often be seen still attached to the tree, but brown and shrivelled, we can see the little holes from which the flies have emerged.

Let us now subject the fly to an examination, and ascertain to what order of insects it belongs. Like other insects, the body consists of three principal parts, the head, the thorax, or chest, and the abdomen, and the

ground colour of the whole is testaceous. The head is small, and furnished with two antennæ of moderate length, composed of about fifteen joints. The antennæ of the female are rather shorter and stouter than those of the male, and have one or two joints less. On each side of the head is a large compound eye, black in colour, and composed of a number of facets, while on the top of the head are three simple eyes of red colour. The antennæ are fuscous in colour for their upper halves or more.

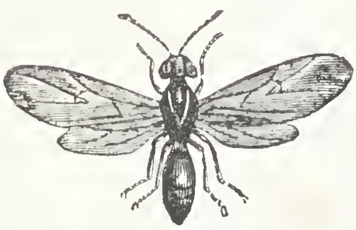
FIG. 2.—A GALL FLY.

If we examine the mouth (and we shall require the aid of a lens in doing so, since the total length of the animal is only about the twelfth part of an inch), we shall find that it is constructed for biting, having two pairs of horny jaws, which, as in all insects and other allied animals, work from side to side, and not from above downwards. The upper jaws, or mandibles, are stout, and the lower jaws, or maxillæ, are more elongate. The mouth is also furnished with a comparatively large fleshy tongue, and other parts which need not be specified.

The chest, or thorax, is comparatively stout, and bears two pairs of wings and three pairs of legs. The wings are formed of a clear, somewhat iridescent membrane, strengthened by a few brown veins. The anterior pair are the largest, and when expanded measure nearly a quarter of an inch from one tip to the other.

The abdomen is attached to the thorax by a short stalk, or peduncle, in the same way as the abdomen of a wasp

or an ant is attached, only less conspicuous. In shape it is oval and very much compressed. The structure differs in the sexes. In the female it is furnished with a peculiar instrument by which the eggs are laid, and this we shall attempt to describe. In the first place, the abdomen, as is usual, is composed of a number of rings, or segments, horny in texture, but connected with each other by a softer membrane. The upper part, or dorsal portion, is also attached by a similar soft membrane to the under, or ventral, portion. If we look at our fly from the side, we shall see that the dorsal part of the segments is curved down at the side to meet the ventral part, and that the ventral portion of the abdomen is terminated by a pointed piece (which is, in fact, the apical segment), with a canal, or gutter, running along the middle longitudinally. In this canal lies the special apparatus for depositing the eggs—a slender, sharp-pointed instrument, called the terebra, or borer. This terebra consists of several pieces, and is protected by two valve-like sheaths, which also lie in the canal. It has a stouter central bristle-like portion, is sharp-pointed, and channelled below for the reception of two more slender bristles, which, by the action of muscles at their base, can work up and down in the canal. The insect, having paired, selects an appropriate place on an oak tree, and bores a hole into it with its terebra. This hole it widens by continuing the action of the instrument, and when it is sufficiently large an egg is put into it, the egg being passed between the three pieces of which the terebra is composed. After the egg has been put in the hole it is pressed still further down by the point of the instrument.

From the characters mentioned above we have little difficulty in assigning the oak-apple fly to a place in the division or order *Hymenoptera,* in which are contained the bees, wasps, ants, &c. The scientific name of the fly is *Dryoteras terminalis* (Figs. 4, 5), and it belongs to the family of the *Cynipidæ,* most of the members of which have life histories and habits very similar to that of the one we have under consideration.

We have still to consider what effect upon the plant the insertion of an egg in the way we have just described has—in other words, how the oak-apple is produced. Unfortunately there is very little to be said about this, and for the best of all reasons, because very little is known. When the fly, whether it be that produced from the oak-apple or whether it be some other member of the family *Cynipidæ,* deposits an egg, it at the same time inserts a drop of some irritating fluid into the hole it has made—or at least it is supposed to do so. The effect of this is to cause the plant to produce a peculiar growth, which is termed a gall—the oak-apples we have been describing are a good example of a gall. Galls have been found on a number of different plants, but at present we are concerned only with those upon the oak. Of these there are a large number of different kinds, occurring upon almost every part of the tree—roots, bark, branches, buds, leaves, catkins, and acorns—but each kind of gall is confined to its own peculiar situation, and is caused by its own special kind of fly. Till the egg that has been deposited hatches no gall is formed, but as soon as the maggot emerges from the egg the gall begins to grow, and its growth is not

interrupted by the maggot feeding on its substance. Should the maggot happen to die at an early period of life the gall is usually malformed. Hence it seems more probable that the growth of the gall is caused—that is,

FIG. 3.—OAK-GALL PRODUCED BY CYNIPS.

that the necessary and peculiar irritation is given to the tissues of the plant—by the maggot rather than by any irritating fluid inserted by the parent insect.

But we have not yet done with the oak-apple fly; in fact, we have only seen about half of its life history, and the not least wonderful part is yet to be described. If we

wish to observe the rest we had better provide some young oak-trees in pots, when they can be covered with gauze. Having done this, we can place upon the tree we have selected some of the flies that have paired, and watch the further proceedings. The time of the year to do this is in July or August.

Remembering that the oak-apples are found upon the *branches* of the tree, we shall be surprised to find that the flies we are watching select the *roots* in which to deposit their eggs. The flies have probably, in a state of nature, little difficulty in finding accessible roots for this purpose, but in the trees that we have potted we must take care that the root can be got at. The galls that result from the puncture of the insects are usually crowded in masses. The individual galls are about the size of a pea, and are rounded in shape, but when in mass they are often fused together, and become irregular. In colour they are reddish, in texture they are woody, and each contains a single cavity, in which lives one maggot, whose appearance is on the whole similar to that of the maggot of the oak-apple. This is surprise the second. These galls are to be found in late autumn, and the insects which are produced from them emerge during the winter. If we were to reason from the case of insects in general, we should expect the insects that are produced to be in form and structure similar to their parents; but after the surprising difference in the situation and structure of the galls we cannot be altogether astonished to find that they are quite different. So different are they that till within the last few years not only were they considered to belong to a

different *species,* but even to quite a distinct *genus:* in fact, that there was no relationship between the two beyond the fact that they belonged to the same family. The name under which the root-gall insect was (and, in fact, is) known is *Biorhiza aptera.* Without entering into a minute description of the differences in structure between it and the oak-apple insect, it will be enough to say that these differences are sufficiently great to have perfectly warranted entomologists in placing them in different genera; and, consequently, when Dr. Adler, of Schleswig (to whom the credit of this and similar discoveries is due), announced

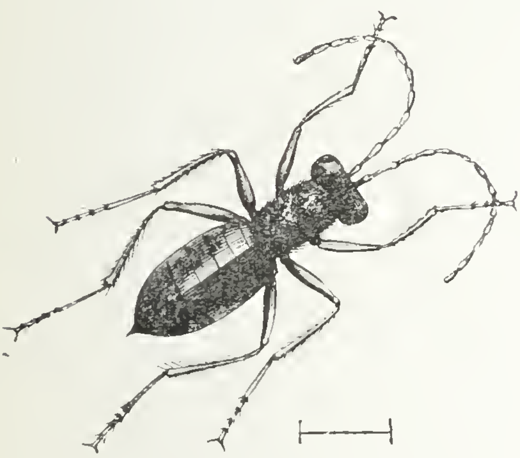

FIG. 4.—DRYOTERAS TERMINALIS (MALE).

that he had found that *Biorhiza aptera* (the oak-root gall-fly) was the product of the eggs of *Dryoteras terminalis* (the oak-apple fly), his statement was received with great incredulity. Some differences may be mentioned: *Biorhiza aptera* is a larger insect than *Dryoteras,* and more variegated in colour, being testaceous and black; the wings are absent (hence the specific name, *aptera*), and the ovipositor is longer. But a more

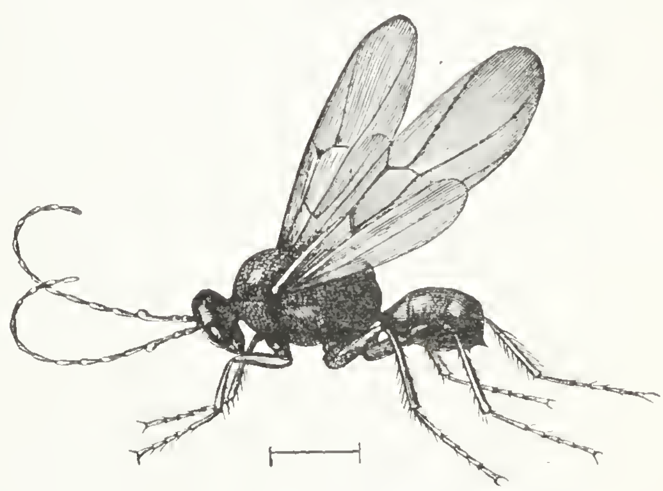

FIG. 5.—DRYOTERAS TERMINALIS (FEMALE).

striking peculiarity remains to be mentioned, and that is that all the specimens belong to one sex—the female—while in *Dryoteras* both males and females occur (Figs. 4, 5).

Let us now continue our observations of the life history of these wingless creatures. They, as we have mentioned, emerge from the galls during the winter, and in the spring, before the buds of the oak-trees have begun to swell, they crawl up the bark, and selecting buds, bore into them with their ovipositors and lay their eggs. As they must reach the heart of the bud, it is evident why the ovipository instrument is longer than in *Dryoteras*, which has only to puncture the skin of the root. These punctures give rise to the oak-apples already described, and in due time to the oak-apple flies. So generation after generation is produced, the oak-apple or bud-galls alternating with the root-galls, and the winged insects, or *Dryoteras*, with the wingless form, or *Biorhiza*.

Though we have said that wingless insects produced from the root-galls are all "females," it would be more correct to consider them as asexual. Long before Dr. Adler made his wonderful discoveries, these asexual forms were well known, and were then considered to be females. The males were supposed to exist somewhere, though no entomologist had ever been able to find one. This was not from lack of interest in the subject; and it is now amusing to read of the immense trouble taken not so many years ago in the vain endeavour to discover the missing males.

For example, we read in a magazine published less than twenty years ago that an entomologist had procured a bushel of one kind of gall, and reared from it nothing but

female flies; that another had examined 10,000 flies reared from another kind of gall, and that all proved to be females; and so on; the writer of the article finally suggesting as a possible explanation that the males came out of one kind of gall and the females out of another.

The oak-apple fly is not the only oak-gall fly in which this curious phenomenon of an "alternation of generations" (as it is termed) has now been proved to exist. Some other instances may be mentioned.

The Cotton Gall (produced by the insect called *Andricus ramuli*) grows upon the catkins, and is a very different-looking object from the oak-apple. It is like a mass of white cotton-wool, but when examined, is found to consist of a mass of small, hard, and thin-walled galls, each of which is covered with a coat of long, dry, twisted hairs resembling cotton-wool. The galls may be found in May and June, and the perfect insects appear in July, and both sexes occur. The fly is minute, being under the twelfth part of an inch in length, ferruginous and black in colour, and with slightly hairy wings. After pairing, the females lay their eggs in the buds of the oak. The result is that a very small egg-shaped gall is formed in the bud, but so concealed by the scales that it is not easily seen. The gall is smooth and brown-coloured, and in late autumn it falls to the ground, where it lies till the perfect insects emerge in spring. The perfect insect (which is described under the name of *Aphilothrix autumnalis*) is asexual.

The Currant Gall (produced by *Spathegaster baccarum*) grows either on the catkins or on the leaves. When on the former, a number of galls grow on one catkin, and as

they are green, mottled with red, and appear as if semi-transparent, they look like bunches of currants, whence the name. They, however, are more frequently to be found on the leaves than on the catkins. When on the leaf, they are chiefly on the under surface, but their broad base projects through to the upper surface. Often two of the galls are so close together that they become fused. These leaf-galls are the same in colour as those on the catkins. Internally they are very full of sap, and contain one small cavity. They appear as soon as the leaves burst out of the bud, and grow so rapidly that in the course of a week or so they have attained their full size. The perfect insects (which include both males and females) are produced in June and July.

The fly, which is little more than the twelfth of an inch in length, is almost altogether black in colour, with straw-colour legs, and broad, somewhat pubescent wings. The gall resulting from the puncture by these flies is the well-known "oak-spangle," often so common on the under side of oak-leaves in autumn. The spangles frequently abound to such an extent that the whole under surface of the leaf is covered with them. Very rarely they may be found on the upper surface. In shape they are circular and flattened, with a slight elevation in the centre; in colour they are yellowish, but so thickly covered on the exposed side with tufts of star-shaped reddish hairs, that they seem to be rusty-red. On the side next the leaf they are smooth. Each of them contains a central cavity, in which the maggot lives. While they are still attached to the leaf the cavity is very small, but when they fall off,

which they do about the time the leaves themselves fall, the cavity enlarges, and while they lie on the ground all winter the gall itself assumes a semi-globular shape, and the internal cavity gets still bigger. The flies (which are all asexual, and have been described under the name *Neuroterus lenticularis*) appear in spring, and resemble very much the flies that emerged from the currant galls, though with the differences of structure that caused them to be placed in separate genera.

There are several other spangle-galls whose makers form part of the cycle (or alternation of generations) in the life history of other species : these we may now notice.

The gall made on the leaves by *Spathegaster tricolor* is small, being less than a quarter of an inch in diameter, and spherical. It is greenish in colour, tinged with rosy, with a scanty coat of long white hairs ; in texture it is fleshy, and the internal cavity is large ; the gall is formed in May, and the perfect insects (male and female) come out in July. The flies are about the twelfth of an inch in length, and are black, spotted with reddish, and with the legs bright yellow. The wings are clear, but slightly clouded towards the tips. The galls that result from the puncture by these flies are very similar to the common "oak-spangle," and, like them, are usually situated on the under side of the leaf, where they are not crowded together as the other so often is. In colour they are pale, with little trace of the tufts of hairs that are so conspicuous a feature of the common oak-spangle. If they happen to be placed on the upper side of the leaf, their colour is red. Their internal structure and life history is similar to that of the common oak-spangle,

and the perfect insects (which are asexual) emerge in spring, and were described as *Neuroterus fumipennis*. They are black and testaceous in colour, with smoke-colour wings, darker towards the tips.

The very small galls (only about the twelfth of an inch long by half as broad) that produce *Spathegaster albipes* are situated on the margin or on the midrib of the leaf, and cause it to be distorted. They are oval in shape, and greenish passing into yellow in colour. Though at first slightly hairy they become quite naked, and are produced as soon as the leaves appear, the perfect insects (male or female) coming out about the middle of June. The galls of the second generation are very like the common oak spangles, but are more often found on the upper surface of the leaf, and are besides less hairy and more saucer-shaped, the edges being turned up a little. They occur in autumn, and the insects (described as *Neuroterus læviusculus*) come out in spring and are sexual.

The galls of *Spathegaster vesicatrix* are very inconspicuous, for, in addition to being only about the eighth of an inch in diameter, they are sunk in the substance of the leaf, and cause only a slight convexity on each surface. In form they are circular with a little knob in the centre, from which five lines radiate. In colour they are green, but after the insects have come out they become yellow, and hence more conspicuous. The galls are formed in early summer and the flies come out in July. The galls of the second generation are the well-known "Silky-button galls," so called from their resemblance to small buttons covered with silk thread and with a central concavity at the top,

that ladies use for trimming dresses. They may frequently be found in great numbers on the underside of the leaf, and cannot be mistaken for any other galls. These galls are about the sixth of an inch in diameter, circular in outline, flat below (where they touch the leaf), and convex above with a conspicuous circular depression. They are covered with fine shining brown silky hairs, which are directed downwards over the rounded sides. In the centre of the gall is a small lens-shaped cavity in which is the maggot. The galls are formed in autumn, fall off the leaves about the time that these drop, and lie on the ground amongst them all winter. In spring, the flies, which are sexual and have been called *Neuroterus numismatis*, emerge.

Another species of Spathegaster (*S. aprilina*) comes from oval-shaped galls about the size of a pea, situated amongst the scales of the bud. In colour the galls are yellowish or greenish, spotted with red, and scantily clothed with a few scattered hairs. They are produced in spring, and the flies (male and female) come out about the end of May. The galls that result from the puncture of these flies are situated on the midrib, or chief veins of the under side of the leaf, and are oval, about the seventh part of an inch long, and smooth and shining. At first they are greenish, but become yellow, thickly dotted all over with little red or violet-red spots. The base of each gall is partially enclosed by two little valves or lappets which seem to be formed by the ruptured epidermis of the leaf. The wall of the gall is not thick, but very compact. These galls are formed about the end of summer, and fall off the leaf in autumn and lie on the ground. The flies (which are

asexual) emerge during the winter and spring. It has been called *Neuroterus ostreus*. It will be noticed how different these galls are from the oak-spangles, though the insect that causes them is closely allied to the species that produces the spangles.

Some other species of *Spathegaster* require to be noticed, as the galls of the second generation are produced by insects which differ structurally from those that form the second generation of the species we have just been describing.

The gall of *Spathegaster Taschenbergi* is formed out of the buds. It is about the eighth of an inch long, egg-shaped with a rounded tip, covered with a coat of fine short hairs, so that it appears to be velvety, and violet in colour. It is soft, and the maggot devours the interior till the wall becomes very thin. The galls are formed in May and June, and the flies (male and female) come out about the beginning of July. The galls of the second generation are found on the back of the leaves, and in shape and size are like the "marbles" that boys play with. In colour they are bright red or yellow, and in texture very soft and spongy, with a small cavity in the centre, in which the maggot lives. The galls are found in summer, and the perfect insects (which are asexual) come out in early spring, and are black and red in colour and about the sixth of an inch in length. To them the name of *Dryophanta scutellaris* has been applied.

The galls of *Spathegaster verrucosa* are attached to the veins and midrib of the young leaf, and are spindle or club-shaped, and less than the fifth of an inch in length. The colour is at first bluish-green, but afterwards greenish-yellow

with red markings, and the surface is covered with bladder-like hairs. The galls are produced in spring, and the flies (male and female) come out in the beginning of June. The galls which they produce (*i.e.*, those of the second generation) occur on the underside of the leaves, and are often very abundant. They are attached by a point to the midrib or veins, and resemble a considerably-flattened sphere, with a smooth shiny surface dotted over with scattered and flattened warts. The colour is pale yellowish brown, but one side is often red. The diameter of the gall is about the third of an inch. The galls are formed in autumn, and the perfect insects (which are asexual, and have been described as *Dryophanta divisa*) appear in winter.

We have still some other galls to notice.

The galls of *Andricus pilosus* occur amongst the stamens on the male catkins, and are very small (about the twelfth of an inch long) and inconspicuous. They are egg-shaped, with a slight longitudinal furrow on the middle of each side ; brown and covered with short stiff hairs, and with very thin walls. The galls are formed in spring, and the perfect insects (male and female) appear in June. The galls of the second generation are much easier to find, being in fact very conspicuous. From their resemblance to miniature artichokes they have been called "artichoke galls," and occur in the buds in autumn. The gall in reality consists of two parts, the outer covering which is composed of the enlarged scales of the bud, which forms a conical mass an inch or more long by nearly as much broad. In the centre of the bud is the true gall, shaped like a little

rifle-bullet, and with a compact shell which encloses the rather large cavity in which the maggot lives. The flies (which are asexual) come out in spring. They have been described as *Aphilothrix gemmæ*.

The gall of *Andricus gemmatus* is exceedingly small, and is found in the buds in summer. It is at first green and then brown, and has very thin walls. The galls of the second generation are imbedded in the bark, and are rather peculiar in structure. The favourite situation for them is the spot where the new bark has grown round the edge of a felled stump or a lopped branch. Here they form hemispherical or oval swellings, fleshy in texture, and covered with a reddish yellow skin. The true gall is found below this and has a compact wall, the upper end of which falls off as a scale, as does also the outer fleshy swelling, when the perfect insect (which is known as *Aphilothrix corticis* and is asexual) is ready to emerge. The galls are formed in autumn, and the insects come out in spring.

A commoner and very different gall is that of *Andricus curvator*. It is found usually on the leaf-stalk, but sometimes on the midrib or veins of the leaf. Frequently, if the leaf has been punctured in the bud, the blade is scarcely developed or represented only by narrow pieces here and there along the side of the gall. The galls are irregularly rounded or slightly lobed, a quarter of an inch in length, but often fused together so as to make larger masses. Externally yellowish-green, smooth, and naked, if situated on the blade of the leaf they project from both surfaces. The external wall is hard and woody, and encloses a large space in which lies an inner gall of small size, brown in

colour, and with a thin paper-like wall. It is attached by one point to the outer wall, but frequently gets detached and lies loose in the cavity. In the case where several galls have become fused together, the inner galls always remain distinct. These galls appear as soon as the leaves burst out of the bud, and the flies (male and female) emerge at the end of June or beginning of July. The galls of the second generation are small, being inconspicuous bud-galls, and remain hidden amongst the scales. They are spindle or egg shaped, smooth and brown and very thin-walled. The asexual insects which they produce (known as *Aphilothrix collaris*) appear in spring.

Another peculiar gall is caused by *Andricus inflator*. It grows on the ends of the young twigs, and forms swellings there. On making a section of the swelling a cup-shaped cavity is disclosed, at the bottom of which lies a very small inner gall, brown and egg-shaped, with a very thin wall. This inner gall is attached in the cup at only one point, and is easily detached when mature. The cup itself is closed above only by a thin membrane. These galls are found in summer, and the flies (male and female) are developed in July. The galls of the second generation are bud-galls, globular in shape, green and smooth, small, and much concealed by the scales of the bud. They occur in autumn, and the insects they produce emerge in spring, are asexual, and have been described as *Aphilothrix globuli*.

The gall of *Trigonaspis megaptera* grows upon the lower part of the trunk, and appears to spring from the bark, but a careful examination will show that it

Fig. 6.—GALLS OF TERMINALIS DRYOTERAS, OR "OAK-APPLES."

really arises from an ill-developed bud. They are comparatively large, varying in size from a quarter to half an inch in length. They are irregularly rounded in form, but when, as sometimes happens, there are several together, they become polygonal from mutual pressure. Often they are almost concealed by the moss which grows upon the trunk of the tree, and then they appear as small red bodies peeping out from amongst the moss. In colour they are somewhat variable, but usually rosy or red. In texture they are fleshy, with a central cavity for the maggot. The galls may be found in early summer, and the perfect insects (which include both sexes) come out in June. From their punctures the galls of the second generation are produced and are very different from those of the first generation. At first they are very small, not so big as the head of an ordinary pin, but as they usually occur in masses of six or more they are not so inconspicuous as might be imagined. They grow upon the veins of the under surface of the leaf, and are at first greenish in colour and kidney-shaped in form. After a while they enlarge and become three or four times their former size, they lose their kidney-shape and become nearly globular, while their colour changes to dirty white. After this they fall on the ground, where they remain all winter, and the perfect insects, which are asexual, emerge in spring. The name of *Biorhiza renum* has been applied to them. It will be remembered that the second generation of the oak-apple gall-fly is also a *Biorhiza*, but the galls it constructs are very different from those just described.

The examples given above will be sufficient to show that the oak-apple is not the only oak-gall whose maker exhibits this very remarkable feature of an alternation of generations. To appreciate the difference in the structure of the insects of the two generations would require the special training of an entomologist, so we have not dwelt at any length upon that, but the difference in the form and situation of the galls can be understood by every one. We must now pass on to a consideration of some other oak-galls. The first place amongst these must be given to the galls or the nut-galls of commerce, which though they do not grow upon our British oak, yet, from their importance to mankind, must always be regarded with great interest. The tree on which they grow is a small shrubby oak, the *Quercus infectoria*, which grows in Asia Minor, and the insect which produces them has been called by various names, such as *Diplolepis Gallæ tinctoriæ*, *Cynips Gallæ tinctoriæ*, and *C. scriptorum*. The galls themselves (as they are imported) vary in size and shape, but may be described as usually about the size and form of a boy's marble, round and hard, externally smooth but furnished here and there with tubercles. In commerce they are known by various names, derived either from the place from which they have been exported, as Levant galls, Syrian galls, Turkey galls, Smyrna galls, Aleppo galls, &c., or from their external appearance. From the latter they are classed either as blue, green, or black galls, or as white galls. The latter are larger and paler, and show generally a small hole, indicating that the fly has emerged. They are hence less valuable than the other

class, which have been gathered before the emergence of the perfect insect. Internally the galls are rather solid, yellowish-white in colour, and with a small central cavity in which the maggot dwelt. These galls, or rather the materials which may be extracted or manufactured from them, are of great importance commercially, being used for dyeing, ink-making, and in photography and medicine. Amongst the substances which they contain is tannin, gallic acid, ellagic and leuteogallic acids, &c.—of which the most important is the gallic acid. The galls really contain a comparatively small quantity of gallic acid and a large quantity of tannic acid, but when the latter is moistened and exposed to the atmosphere it absorbs oxygen and is converted into gallic acid, &c. Gallic acid, when heated to 410° Fahr. is converted into another valuable substance, pyrogallic acid. Many of our British oak-galls have a similar chemical composition to the galls of commerce, but are said not to be sufficiently rich in the special constituents to be of economic value.

A gall somewhat similar in appearance to the Levant galls is one to which the name of the "Devonshire galls" (from the place where they were first noticed in Britain) or the "marble galls" (from their resemblance to boys' marbles) has been given. These galls are produced by *Cynips Kollari*, and are supposed not to be indigenous to Britain, but to have been introduced in some unknown way. At any rate, they are now common in many places, though it is not very many years ago that they were first noticed. The galls are produced on the buds of the young branches, and are almost perfectly spherical, with a smooth

surface or with occasionally a few warts. At first they are yellowish-green in colour, and rather fleshy, but as they get older they become brown and dry. Internally they are spongy, with a very small central cavity, and thin, hard, compact walls. They remain on the twigs for years, and hence are easily noticed when the leaves have fallen.

The perfect flies are all females, or rather asexual, the perfect male and female being unknown. This fact suggests that the Devonshire gall is merely the gall of the second generation, and that the gall of the first generation remains to be discovered. Many thousands of the flies have been reared and examined, but the result has been the same—no males can be found. We may here mention a fact to which we have not hitherto alluded—namely, that in addition to the rightful occupant of the gall, it is very often inhabited by other species of insects. These may be divided into two classes—"parasites" and "guests." The parasites feed upon the rightful owner of the gall, and usually belong to the order *Hymenoptera*. Some of them are the well-known ichneumon flies, which deposit their eggs inside caterpillars and other larvæ, the result being that the parasite feeds upon the flesh of its victim, taking care to avoid any vital part, till it has attained its full growth. It would naturally be thought that the thick walls of the gall would have protected the inmate from such attacks, but these parasite-flies are provided with long ovipositors with which they pierce the gall, search out the inhabitant, and deposit an egg in it. The guests, or, as they are called, "inquilines," do not on the other hand

feed on the owner of the gall, but on the substance of the gall itself. Almost all orders of insects are represented amongst these inquilines. Some do not usually feed upon galls, but are attracted thereto by finding a supply of nutritious food ready for them; others, on the contrary, live nowhere else but in galls.

Other insects occasionally make use of the old galls as habitations. A quotation from old Gerard is interesting as showing that these things had been noticed even before his time. Speaking of oak-apples, he says, "The oke-apples being broken in sunder about the time of their withering, doe foreshew the sequell of the yeare, as the expert Kentish husbandmen have observed by the living things found in them: as, if they find an ant, they foretell plenty of graine to ensue; if a white worm, like a gentile or maggot, they prognosticate murren of beasts and cattele; if a spider, then (say they) we shall have a pestilence, or some such like sicknesse to follow amongst men. These things the learned also have observed and noted: for Matthiolus, writing upon Dioscorides, saith that, before they have a hole through them, they containe in them either a flie, a spider, or a worme; if a flie, then war ensueth; if a creeping worme, then scarcitie of victuals; if a running spider, then followeth great sicknesse and mortalitie."

Before concluding, two other galls may be noticed. One is that formed by *Andricus glandium*, and is to be found inside the acorns. No marked external deformity is caused, but on cutting open the acorn a number of cavities of small size, each enclosed by a thin hard wall, will be

found. In these the maggots live. It has been observed that the maggots may remain in these galls for years after they have been gathered, without undergoing any change.

The last gall that we will call attention to is rather a celebrated one. Many persons who are familiar with Moore's lines on

> "Dead Sea fruits that tempt the eye,
> But turn to ashes on the lips,"

may yet be unaware that there are true galls, which infest a species of oak. Though known from time immemorial (for do not Tacitus, Strabo, and Josephus mention them?) it is but only comparatively recently that the true nature of these "mala insana," or "apples of the Dead Sea," has been discovered. They are about two inches long by an inch and a half wide, of a rich glossy purplish-red externally, but internally spongy and easily pulverised, and intensely bitter. The insect which produces them has been called *Cynips insana.*

The galls that we have noticed in this paper are only a very few of these singular productions. Upwards of sixty kinds are known to grow upon the various species of European oaks, while many other kinds of plants produce various kinds of galls. Almost every order of insects possesses a greater or less number of gall-makers, but the most interesting are those of which we have given some account above, and which exhibit the truly wonderful phenomenon of an alternation of generations, or, as it is otherwise termed, dimorphism, in the galls and their makers. They are not, however, the only insects which

exhibit this. Some members of the family of the *Aphides* (or "green-flies") have long been known to have an alternation of generations, which has recently been shown to possess several curious features hitherto unsuspected—namely, that the alternate generations infest different kinds of plants and migrate from one to the other.

Though many advances have been made in our knowledge in recent years, there yet remains a great deal to be learned. We smile at the ideas of the old philosophers who thought that galls were produced by the eggs of insects which had been deposited in the earth, and thence taken up by the roots of plants and carried through various vessels, along with the sap, to the place where they were to hatch and form the gall. Equally, or more ridiculous, seems to us the conjecture of the Italian naturalist Redi, who, after successfully proving the absurdity of the ancient ideas of spontaneous generation, brought forward the extraordinary theory that the same "vegetative soul" by which, as he supposed, plants were produced, was instrumental in creating the maggots which he found in galls, and for whose existence he could not otherwise account.

But, after all, what a little way our knowledge extends. We know, indeed, that galls result from the deposition of eggs in certain plants by certain insects, but we do not know the means by which the plant is compelled to devote part of its protoplasm to build up the gall. We cannot yet explain why two very similar kinds of insects are enabled to affect so very differently one and the same organ of the

plant; or how the first generation of the dimorphic species produces such very distinct galls from the second generation. But many able observers are at work on this interesting subject, and doubtless some day light will be thrown on it, and much that is unintelligible now will be clearly explained.

COMETS.

By Geo. M. Seabroke, F.R.A.S., Temple Observatory, Rugby.

From the earliest times of which there is any record we read that man has looked upon comets with amazement and awe. Appearing, as they often do, early in the evening in full brilliancy in the heavens, in some position amongst the stars where no body of such sort existed when that spot was looked upon the day before, they are sure to cause the superstitious and the followers of Zadkiel to look forward to some event dreadful and dire; and those who are sceptical of astrology to examine, wonder, and theorise on the constitution of these wonderful visitors, and to ask themselves from whence they came and whither they are going.

At the astonishment of the ancients we cannot wonder, for the appearance of a large comet is one of the most imposing of natural phenomena. Owing to the superstitious dread occasioned by the appearance of comets in times past, and to the attention paid to their movements, such appearances were carefully noted down by the ancients as things not to be forgotten; hence the record of a large number of visits by these bodies has been handed down to us, especially by the Chinese, once one of the most enlightened nations in science, and the paths or orbits of more than three hundred of these bodies have been approximately calculated.

Although the number recorded as seen amounts to several hundreds, one list alone containing some 700 comets, still we must remember that these records were compiled before the careful search of the heavens for these bodies, now made with the telescope, was introduced, and therefore only the large and conspicuous ones were noticed. At the present time no year passes without the discovery of perhaps four comets, and sometimes two or more are visible at the same time; large numbers must pass unseen by reason of their orbits lying in such a position that they could be seen only by daylight, by which we well know all but the largest and brightest are totally obliterated from our view.

Now that a thorough examination of the heavens is made night by night, weather permitting, by comet seekers, it does not often happen that a comet appears suddenly after sunset to the casual observer; but of course this is still quite possible, owing to the comet being lost in the sun's rays until it has approached near our earth, and then, having moved to one side or other of our luminary, it appears to us just after sunset or just before sunrise, blazing and conspicuous in manner recorded by the astronomers of old.

When a comet is seen through a telescope, while yet a long way off, it appears as a misty patch only; this, on coming nearer to us and the sun—for we are close to the sun in comparison with the distances from which comets come—increases in size and brilliancy, at the same time the body of the comet becomes elongated, and the brighter portions take up a position on the side nearest the sun; the

comet still gets longer and brighter, and gradually takes the form of a star or planet, called the *nucleus*, surrounded on one side by a luminous mist, called the *coma*, which is drawn out on the opposite side into a tail, often of gigantic proportions. The average comet, therefore, when in full splendour, appears to the naked eye as an ill-defined mass

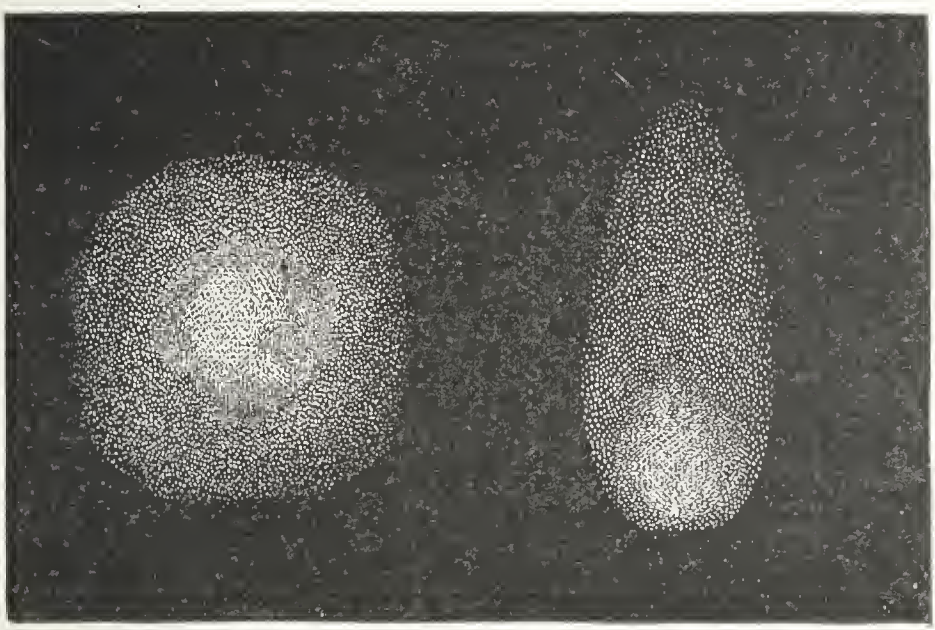

FIG. 1.—EARLY STAGES OF APPEARANCE OF A COMET, SEEN THROUGH A TELESCOPE.

of light, often called the *head*, which includes the nucleus, the coma, or bright haze closely surrounding it on the side towards the sun, and the more extended nebulosity outside the coma. Following the head comes the tail, gradually growing broader and fainter until it is lost to view. Very many comets are visible only with a telescope, and their development advances little from the stages shown in Fig. 1.

We have spoken of the proportions of these tails, and a

few instances will not be out of place here. The comet of B.C. 371 is stated to have had a tail reaching a distance equal to one-third of the way across the heavens, or 60°. That of A.D. 1618 had a tail extending, it is said, 104° in length, that is, 14° further than the distance from the horizon to the zenith; and that of the great comet of 1843 —probably the most magnificent comet of the century— extended 65°. Of still later comets, we have the tail of Coggia's in 1874, extending 40°, and the great comet of 1882, with a tail 23° long.

Some comets, however, do not develop a tail, and on the authority of Sir John Herschell we may state that those of 1585 and 1763 had no vestige of a tail; some do not develop even a nucleus, and other comets have more than one tail.

The apparent motions of comets are strange and capricious: sometimes they appear to move slowly, at other times with great rapidity; the angular course of the comet of 1472 is said to have been as much as 40° in a single day, while others have appeared from night to night in so nearly the same place that their motion is only detected by instrumental appliances.

Comets also move at very different rates while traversing different parts of their orbits; their changes in size, at the same time, being no less remarkable. Again, they do not follow the apparent beaten track of the planets, near to the ecliptic, but traverse all parts of the heavens indifferently, and in all directions. The direction taken by the planets round the sun, which appears to us, when looking from our point of view, contrary to the direction

in which the hands of a watch go, is called *direct*, and the contrary direction indirect, or *retrograde*. We say, therefore, that the motion of comets is both retrograde and direct, and the planes in which their orbits lie are inclined at all angles to that of the earth's orbit, called the ecliptic. Taking the comets generally, the number of those whose motion is direct is so near the number of those whose motion is indirect that no general law is indicated; but of the comets moving in elliptic, or more properly speaking, oval orbits, the number having a direct motion is more than double the number of those that have a retrograde one.

While the planets move round the sun in orbits nearly circular in form, though really true ellipses, and are, therefore, objects always to be seen, when not overpowered by the sun's rays, those comets which are members of our system, and periodically return to our view, travel in paths which are ellipses, though enormously elongated when compared to those of the planets; so that at one time they move very close to the sun, sometimes nearer than the nearest planet of our system—Mercury—and at another, when at the opposite extremity of their orbit, they approach or surpass the distance of our most remote member, Neptune.

Most of the comets recorded are not members of our system at all, or at least their returns are at such long intervals from each other that they are not recognised as such. Starting, therefore, from the comet whose period of revolution is the shortest—namely, Encke's comet, of three and a half years—we find amongst those whose returns

have been recorded, instances of various periods up to that of Halley's comet, of seventy-six and three-quarter years. Going beyond this, we find many comets, to our knowledge, only once seen, and whose returns have been calculated to take place thousands of years hence. For instance, the return of Donati's comet of 1858—a sight long to be remembered by many—will probably take place in not less than two thousand years; and that of Coggia, in 1874, is foretold to be again seen ten thousand years hence. A step further leads us to those comets which will not return at all, inasmuch as they move in an orbit having the form of a parabola, a curve, the two branches of which are continually getting nearer to parallelism to each other, but which never meet; or further still, a comet may have been moving in a hyperbolic curve, the two branches of which for ever diverge. These comets are visitors to our own system, never more to return, but probably going from sun to sun, the vagrants of the universe. Would that we could speak them on the way, as one ship would another in passing, and learn from them the wonders of other systems, and hear them tell of the varied contents of the universe, and whether the physical laws known to us are in force on the confines of space.

To return and speak more concisely: the periodic comets move in ellipses of large eccentricity, while the others move in orbits either parabolic or hyperbolic, and are therefore never seen again. A comet is said to be in *perihelion* when it is at its nearest point to the sun, and in *aphelion* when at its furthest; the perihelion and aphelion distances of a comet are therefore the least and greatest

distances from that body. The known short-period comets are Encke's, having a period of 3·29 years, the perihelion and aphelion distances of which are 32 millions and 388 millions of miles; Winnecke's, having a period of 5·54 years; Brorsen's, having a period of 5·58 years; three of Tempel's comets, having periods of 6 years, 5·1 years, and 5·5 years respectively; Biela's had a period of 6·61 years, but as a comet it probably no longer exists, and more will be said of this comet hereafter (pp. 190 and 218); D'Arrest's, having a period of 6½ years; Faye's, having a period of 7·44 years; Denning's, having a period of 7·75 years; and Tuttle's, having a period of 13·66 years.

Of comets of a medium period we may quote Pons's, seen in 1812, having a period of 71½ years, and which returned to our view at the end of 1833; and Halley's, of which more anon, having a period of 76·78 years, and an aphelion distance of 3,200 millions of miles—far greater than the distance of Neptune, the furthest known member of our system. Then there come the long period comets; that of 1811 has a period of 3,065 years, and an aphelion distance of 40,121,000,000 miles. Coggia's comet of 1874 was calculated to have a period of 10,000 years, and an aphelion distance one hundred times that of the earth's. Findlay's comet of 1882, which is fresh in the memory of many of us, was calculated to have a period of 600 years, but on this, as there always is with comets of such long periods, there was a difference of opinion depending on the admission of certain observations.

To Newton is due the honour of reducing the strange motions of these stranger bodies to order and law. In

1680 there appeared a large comet, remarkable for its immense length of tail and for the closeness of its approach to the sun, the distance being only about one-sixth of the diameter of the latter. Newton had demonstrated the possibility of a body moving round the sun in an orbit of the form of any conic section, under the influence of the law of gravitation, and this comet gave him an opportunity of applying his theory to an actual case. It was visible for some eighteen months, so there was plenty of opportunities for observations. At the same time he invited astronomers to apply his theory to the orbits of comets then already recorded. The application of this theory to the observed places of the comet was eminently successful: its orbit was an ellipse, and the sun occupied one of the foci—but the ellipse was of such great eccentricity that it might be considered to be a parabola, and the comet moved under the same laws of motion as govern the motions of the planets in their nearly circular, but still elliptic orbits. Astronomers were not slow to apply this theory to other comets and to firmly substantiate the fact that comets obeyed these same laws of motion, but that their orbits were enormously elongated when compared with those of the planets, which, as already stated, are ellipses of very small eccentricity, or almost circular in form.

Let us now consider what is approximately the *mass* of comets in general. On this point little is known, and that little is negative evidence only. The comet of the year 1770—Lexell's comet—has furnished us with the best evidence. It was found, from observations made of its

position while passing near the earth, that its period was about $5\frac{1}{2}$ years, and by tracing it backwards on its orbit, it was found to have passed in 1767 very close to the planet Jupiter, less than the distance of his fourth moon, and it remained in the neighbourhood of the planet for about two months. Now, if the comet had any considerable mass, it would by its attraction—that same attraction which gives to objects on the earth what we call weight, and by which Jupiter holds his moons in their orbits, the attraction of gravity—have caused a disturbance among the moons, but no such disturbance was discovered; on the other hand, the comet itself was greatly affected by Jupiter. Calculation shows that prior to its falling in with the planet it had a period of forty-eight years, and its nearest approach to the sun—its perihelion distance—was some 300 millions of miles: too far off to have been seen by terrestrial observers. In the year 1776 the comet should have again passed near the sun, but the earth was not in a good position for it to be seen; and in the autumn of 1779 it would pass very close to Jupiter again, and in consequence of Jupiter's attraction, its orbit would be again altered to one such that the comet would have a period of sixteen years, and a perihelion distance of about the same as at first, namely, 300 millions of miles. This comet has, therefore, not been seen since 1770, and altogether its orbit has been twice altered by the proximity of the comet to Jupiter; but the moons have suffered no disturbance at either time. Again, the same comet made one of the closest, if not the closest, approaches to the earth on record, the distance being only 1,400,000 miles; and it was computed by La Place that if

the mass of the comet had been equal to that of the earth, it would so have altered the earth's orbit that the year would have been lengthened by 2 hours 48 minutes. From this fact it has been calculated that the comet's mass could not exceed one five-thousandth of that of the earth, and from the negative evidence obtained from the absence of disturbance while passing Jupiter, its mass must have been very much less than even that fraction; still, the nebulous matter surrounding the nucleus was of a diameter equal to five times that of the sun.

Bearing on this subject is the remarkable transparency of comets. We should expect that their immense tails, the distance from one side to the other of which is reckoned in millions of miles, would have obscured the stars over which they passed. This, however, is not the case, for even the faintest stars remain visible through the largest tails. In the year 1847 Miss Mitchell discovered a comet which passed perfectly centrally over a star of the fifth magnitude. On the 5th of October the comet appears to have been a circular nebulous mass, with an increase of brightness towards the centre, but without a nucleus; the star, therefore, was covered by the densest portion of the comet, and occupied the apparent place where the nucleus should have been, but its brilliancy was not in the least decreased. Again, stars were seen perfectly through the immense tail of Donati's comet in 1858, and through the tail of our late visitor in 1882. These tails are more transparent than a puff of smoke or the slightest cloud. Still, there is a sufficient quantity of matter present in the tail to intercept the sunbeams and reflect the light to our view. We

may perhaps compare the constituent matter of a comet's tail to the dust-like matter floating in the higher regions of our atmosphere—that matter which intercepts the rays of the setting or already set sun—be that matter particles of water, ice, meteoric dust, or the minute fragments of volcanic origin thrown up by Krakatoa or other mountains in eruption. To the dust from Krakatoa the magnificent sunsets of 1883 were attributed; but to whatever cause these remarkable phenomena were due, there is a sufficient quantity of floating particles in our atmosphere to reflect light probably as strong as any tail of one of our brightest visitors; yet we see the smallest stars through our atmosphere, and we are not aware that there has been lately any marked obscuration owing to the presence of the matter causing these splendid sunsets. In this we may have a hint as to the constitution of comets' tails. Although the light is so faint from the tail of a comet that a trace of moonlight strips it of its splendour, still the head of a comet shines much more brightly; and some have been visible by daylight, even when in close proximity to the sun. As an instance of such a case, the large comet of 1882 was discovered by Mr. Common at Ealing on the morning of the 17th September in that year, while close to the sun, and, as we shall presently read, he watched it until it approached within half the sun's diameter from its edge; by others it was seen to enter the sun's disc. Then there is the comet of 1843, which was well seen in close proximity to the sun; also there are those of 1402 and 1532, which were visible in the same manner. There are other recorded instances of similar cases of visibility in

the daytime; the first relates to a comet seen B.C. 43, and there are some other similar instances recorded.

Bearing upon the question of the constitution of comets, and as evidence that they do not consist of a solid mass, like one of the planets, with a tail to it, are the curious instances of the separation of a comet into two parts. There are records of the comets of the years B.C. 371 and A.D. 1618 having divided, but the best authenticated instance is that of Biela's comet, which happened so lately as to be within the lifetime of many of us. This comet, of which we shall say more hereafter, was predicted to appear in 1845, and it was seen on November 28th approaching the sun as a faint circular nebulosity, condensed slightly towards the centre. Although the comet was small and scarcely visible to the naked eye, it attracted the attention of every astronomer by its subsequent wonderful division into two parts. On December 19th, 1845, Mr. Hind noticed that the comet appeared pear-shaped, the nebulosity being elongated in a northward direction. This was the first indication of anything going wrong with the comet. By the end of the month the comet had separated into two parts; for on the 13th of January, 1846, the comet had a small one travelling in its company, and each comet was seen to have a distinct nucleus; one comet was, however, much smaller than the other. The separation of the two comets went on increasing all through the month of February, and by the 5th of March the angular distance between them was 9′ 19″—equal to a little less than one-third of the moon's diameter. We must, however, bear in mind the fact that during this time the comets

were approaching the earth, so that part of the observed increase in angular distance between the comets was due to our growing proximity to them. According to Professor Plantamour, the increase of distance after the 10th of February until the 22nd of March was apparent only, being due entirely to the approach of the comets to the earth. Not only was there a mere separation, but there appears to have been a continuous interchange of cometary matter taking place between the two bodies as they travelled onwards. When first seen, the small one was extremely faint, but it gradually grew in brightness until the 10th of February, when it was equal in splendour to the original one. For the next few days it still increased, and became superior in apparent magnitude to the old one; but this superiority was short-lived, for by the 18th of the same month the old one was twice as bright as the new one, and its nucleus became very well defined and star-like. The decrease in brightness of the companion continued, and on the 24th of March it became lost to view, leaving the original comet only visible. A ray of light appeared to join the two comets together while this curious alternation of brightness continued, and it was along this, as a kind of bridge, that the cometary matter may possibly have passed from one to the other.

The actual maximum distance between the two bodies occurred on the 3rd of March, and was then about 157,240 miles—equal to about two-thirds of the distance between us and the moon, or six times the distance round the earth. By the 22nd of April in the same year the comets had disappeared in the distance.

The next return of this remarkable body was predicted to take place in the autumn of 1852, and it was not without anxiety and speculation that it was looked for. Safely enough, in August of that year it was seen—or rather, we should say *they* were seen, for travelling on together were the original comet and its companion, still retaining the same relative positions with respect to each other, but at an increased distance: it had by this time become 1,250,000 miles. Thus, clearly, there had been a permanent addition to our solar family, and this had taken place under our very eyes.

We shall have more to say of this curious comet as we progress further. This is not the only instance of the division of a comet; that of 1618 showed a tendency to break up, and a comet seen in the early part of 1860 by M. Liais is reported to have been accompanied by a smaller nebulosity.

By far the most important part of a comet in point of size is its tail, although, as we have already stated, some large comets are recorded as being without tails, and as having well-defined discs, like the moon and planets. The comet of 1652 is said to have been almost as large as the moon, though not so bright, and those of 1665 and 1682 are reported to have had well-defined planetary discs. Small comets often have either no tail or one of the most rudimentary sort. From the tailless comets we pass through all stages of splendour up to lengths of hundreds of millions of miles, but the chief point to be noticed about tails in general—we mean, of course, comets' tails, for in this particular they differ from those of animals—is that

they do not always follow their respective heads, as of course by the ordinary conventional rule they should do. Comets do not seem to like to follow the rules of ordinary beings, for during the passage by the comet of that part of its orbit in which it is receding from the sun, its tail leads and the head follows. In fact, the general direction of the tail is in that opposed to the sun, while it has a curvature backwards, as if the further end were being left behind. It is from this general fact that we get a hint of their constitution. As the comet first appears in its approach to the sun, its tail, if any, is short and faint, and follows the head. The tail increases in size, and continually takes up the position in a direction opposed to the sun, even so far as to precede the head during its recession from that body.

Comets usually have one tail only, but there have been many exceptions: the comet of 1744 had six tails; one that appeared in 1825 had five tails; while Donati's comet, in 1858, had for some days a faint streamer, and at one time two such appendages of great length extending alongside of the large tail. Again, the tail of the great comet of 1861, on June 30th, appeared as an immense fan of light, the two extreme streamers making with each other nearly a right angle at the nucleus.

Sometimes pulsations of light have been seen to pass from the head of a comet along the tail, in the same manner as the waves of increased luminosity travel along the streamers of the Aurora Borealis. Mr. With, of Hereford, describes a similar appearance which he saw while looking at Coggia's comet on July 8th, 1874, as follows:—"A

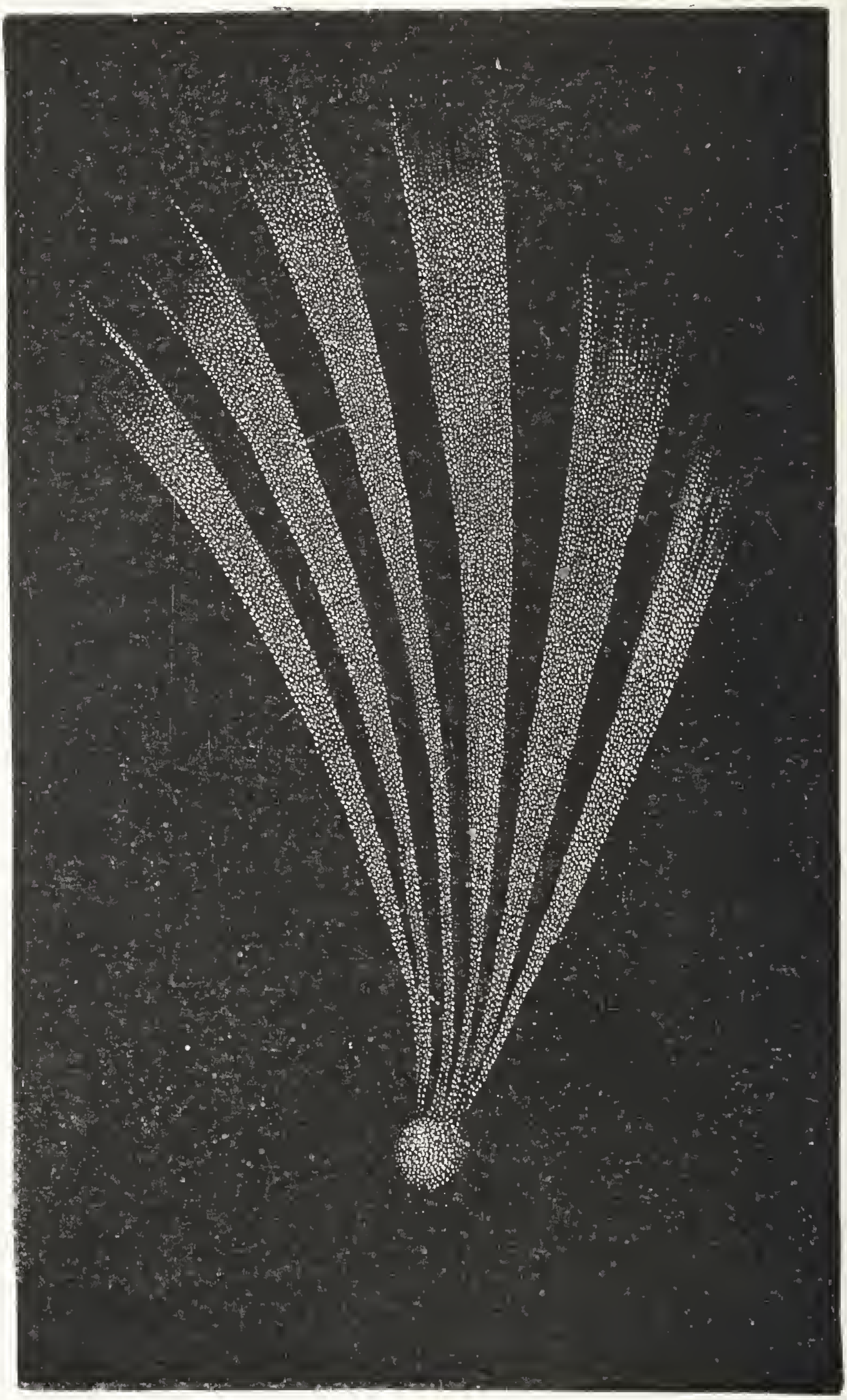

FIG. 2.—SIX-TAILED COMET OF 1774.

remarkable oscillatory motion of the fan-shaped jet upon the nucleus as a centre occurred at intervals of from three

to eight seconds. The fan seemed to 'tilt over' from the 'preceding' towards the following side, and then for an instant appeared sharply defined and fibrous in structure. Suddenly it became nebulous, all appearance of structure vanished, and the outline became merged in the surrounding matter. At the moment of this change a pulsation was transmitted from the head through the coma, as though luminous matter had been projected from the former into the latter." Although this is by no means the only observation of wave-like appearances, still there is very strong reason for believing that such phenomena are due to changes in our own atmosphere, and not to actual pulsations of the comet. The tails of comets are usually brighter near their margins than in the middle, where they fade away, so as to give the appearance sometimes of two tails; they also get wider across as the measurements recede from the head. These facts point to the structure of the tail being that of a hollow cone, for in such case we should look through a greater thickness of matter near the margins than we should in the middle; and a black space is often seen immediately behind the nucleus.

The variation in length of tails of different comets is great, while even in a short time the tail of the same comet may change its length enormously. On August 8th, 1769, a round nebulous body was discovered by Messier, which turned out to be a comet. On the 15th the tail appeared 6° in length; on the 28th, 15°; on September 2nd, 36°; on the 6th, 49°; on the 10th, 60°. The comet on the 8th October passed its perihelion, and for some

days before and after was lost in the sun's rays; on the 24th October its tail was only 2° long, one-thirtieth of the length when last seen, and on November 1st it had increased to 6°, after which it diminished until the disappearance of the comet. The tail of the great comet of 1811 elongated at one time at the rate of 9,000,000 of miles a day; that of Donati's comet, in 1858, increased 2,000,000 of miles a day; and the comet of 1843 appears to have shot out a tail at the rate of 35,000,000 of miles a day, which became eventually 120,000,000 of miles in length. These enormous proportions are obtained when the comet is in close proximity to the sun.

Spectrum analysis has of late years made such rapid strides in its application to astronomy that we may reasonably look to that branch of physics to enable us to unravel the mystery of these extraordinary bodies. Space does not allow us to go into details, but for the benefit of those of our readers who are not versed in spectrum analysis, we may state that the light falling on the narrow slit of the spectroscope is spread out by one or more prisms into a band, called the spectrum, having, when white light is used, all the colours of the rainbow, because white light consists of a mixture of all those colours. But if certain colours be absent, their places in the spectrum will be left as dark spaces, or if only certain colours are present, they will appear in their proper places on the spectrum as bands or lines on a dark background, according to the purity of the colours. It is a generally observed fact that gases and vapours, when in a state of incandescence, give off light producing bright lines or bands in the spectrum, and such

lines or bands are specially placed, and are characteristic of the gas or vapour so producing them; while liquids and solids give off light of all colours and produce a continuous spectrum; but to this generalisation there are exceptions. Therefore, if on examining the light of any heavenly body we see one or more bright bands or lines, we may reasonably conclude that there exists a gas or vapour giving us such light; and we can compare the position of the bands or lines in the spectrum with those in the spectrum of some gas or vapour in our laboratories, and so discover of what the material of the luminous body in the sky consists.

If we examine the light of a comet in this manner we find generally that, firstly, the light from the nucleus produces a continuous spectrum; secondly, the light from the coma and that part of the tail which is sufficiently bright to give a spectrum, produces three, and sometimes four, bright bands, which exactly correspond with the bands produced by the light of a spirit-lamp flame, the blue base of a gas flame, and light of many other compounds of hydrogen with carbon; thirdly, the light from the coma and tail also give a very faint continuous spectrum as a background on which the bright bands appear.

We interpret these observations as follows: The nucleus contains either liquid or solid matter in a state of incandescence, or reflecting the light of the sun, in order to give the continuous spectrum; the coma and tail is gaseous or vaporous in order to give the band spectrum; and the chief constituent of the coma and tail is some form of a hydro-carbon. The faint continuous spectrum

is accounted for on the supposition that there are a quantity of minute solid or liquid particles in the coma and tail, which act in the same manner as the nucleus, but in a much less degree. It is true that the spectrum of sunlight is a continuous one, crossed by an almost infinite number of black lines, and therefore we ought to be able to say whether it is reflected light or not that is given off; but owing to the faintness of the cometary spectrum, excepting that part from a bright nucleus, these lines would not be seen if present. Unless, therefore, the nucleus is sufficiently bright to show the black lines, if present, we are unable to say whether it is reflected sunlight or not that it gives off; but comets have appeared whose nuclei have decidedly shone by their own light, and even the presence of the vapour of the metal sodium in an incandescent state about the nucleus has been clearly indicated by the presence of its characteristic bright lines in the case of the comets of Wells and Findlay. It often, however, happens that the spectrum of a comet consists solely of the bright bands, without any continuous spectrum from even the nuclei, indicating the presence of a hydro-carbon vapour only.

We have now gone through most of the observations made upon comets which bear on the great question of their constitution, and we may therefore commence to generalise upon them. As to the nucleus, we may argue that it consists of a loose aggregation of rocky or earthy matter, having a constitution similar to that of the meteoric stones which have been picked up after their fall upon our earth, and deposited in our museums for examination. In

addition to this, there exists diffused through the mass some hydro-carbon, which is evaporated by the sun's heat, and in condensing, forms a quantity of particles of almost infinite minuteness, which together form the tail.

The steam from the funnel of a locomotive condenses and forms the cloud which is present; but the condensed steam and smoke from the locomotive is left behind, because the air resists its onward motion with the engine, and brings it to rest, or wafts it along in the direction of the wind. There is, however, no air or other sufficient resisting medium in the path of the comet to hold the tail behind, as the air does the condensed steam, and if there were, it would not account for the tail leading the head when the comet is receding from the sun. We must therefore look for another explanation; and since the tail is always lying in a direction such as should be the case were there a constant wind blowing from the sun at an enormous velocity, it may be safely assumed that there is some repulsive action exercised by the sun on the matter forming the tail. The introduction of this repulsive action seems contrary to all our experience, for all our theories of planetary motion are based upon the attraction of gravity, which appears to obtain everywhere throughout our system. Bodies on the earth have weight because the earth attracts them; the moon is kept in her orbit for a like reason, and the earth is also held in her path by the attraction of the sun; or rather, we ought to say that these things happen through the joint attraction of both bodies concerned on each other. If we bear in mind that the smaller an object becomes the larger proportion does the

numerical value of its surface bear to the numerical value of the quantity of matter contained, we can conceive bodies so small that the slightest action on their surface overcomes the minute effect of gravity. For instance, the particles of carbon issuing from a chimney in the form of smoke, and the minute motes always floating in the air, and shown up when a sunbeam passes through a darkened room, appear to have released themselves from the power of gravity, and to disobey its laws; the slightest air wafts them onward, and we have no experience of their falling, except by the slow accumulation of dust on objects in quiet situations.

Imagine, then, the particles forming the comet's tail to be more minute than the particles of carbon in smoke, or the motes in the air, or anything we have to deal with here: more like, perhaps, the meteoric dust, that product of the condensation of the vapours of meteorites evaporated by the intense heat produced by friction in passing through the higher regions of our atmosphere. On these particles a repulsive action, depending on the surface exposed and not on the matter inside, would overcome the action of gravity. It must, however, be borne in mind that we have no actual experience of such a repulsive force existing in the sun. It is true that bodies when charged with electricity of the same kind repel each other, and it is possible that by the evaporation of cometary matter a state of electric charge may be set up in the evaporated particles; we also are aware that heated bodies exercise a repulsive action on the dust in the air, but it does not follow that this law holds good in a vacuum such as that in which a comet moves,

although this latter is the more probable explanation. On this point we are leaving the land of experience and embarking on the ocean of speculation.

On the hypothesis, therefore, of matter being continually emitted from the nucleus, owing to evaporation occasioned by the sun's heat, and drifting backwards again by a repulsive action due to the sun, the position and form of a comet's tail is fully accounted for; the existence of two tails is also consistent with it, for we have only to imagine that a certain set of the emitted particles, by reason of their greater minuteness, or from some other cause, are repelled by the solar agency at a greater velocity than others, when they will take up a position nearer to that of a straight line drawn from the nucleus in a direction opposite to the sun. Other forms of tails, such as the fan-shaped one of 1861, may have been due to foreshortening, thereby causing the wider portion of the tail to be enormously exaggerated in apparent proportion.

There is no necessity to assume the existence of any enormous repulsive force to drive the particles away to form a tail, for it has been shown that a force a little greater than twelve times that of the attraction of gravity would be sufficient to account for the straightest of tails; while tails of the most commonly curved form would be produced by a repulsive force about double that of gravity, so as to overcome the latter, and leave as balance a repulsive force equal to it.

M. Faye has hit upon a very happy illustration of the formation of the matter forming the tail by evaporation due to the sun's heat. He says: "Let us consider a snow-

flake carried into celestial space, where there is no medium to exercise any pressure and to retain the heat of the sun. On the side on which the flake received the solar rays its temperature would rise, and it would give off vapours which would expand with a certain speed; but these vapours, too rare to retain their heat, would soon condense into much smaller flakes. These, in their turn, under the influence of the solar rays, would give off vapours, to be condensed almost immediately, like the former vapours, by the cold of surrounding space, in such manner that the action of the sun, counterbalanced by no sensible attraction towards the centre of the original flake, would tend to decompose it into a nebulosity suffused with unstable vapours, exceedingly rare, and soon occupying an enormous volume. In this state the substance is fully prepared to submit to the action of repulsive forces, from which the solid and infinitely dense materials escape by reason of their very density." The evaporable materials on the sunny side of the nucleus are in the place of the snowflake, and while they, or their products of combustion after evaporation are of sufficient size and density, they proceed onwards under the attractive influence of the sun dividing and dispersing themselves in front of and around the nucleus, producing thereby the bright coma and fainter envelopes beyond. Soon, owing to subdivision, the repulsive action of the sun overcomes that of attraction, and the matter is, as it were, wafted backwards in the form of a hollow cylinder or cone: just as a slight wind blowing downwards soon overcomes the tendency of smoke to rise from a chimney top, and carries the smoke downwards, surrounding the chimney.

We have seen that Biela's comet divided into two parts, and others—notably, that of 1882—showed a tendency to break up. Why is this? Our earth does not appear likely to divide into separate parts, nor do the other planetary members of our system. But still there does exist a tendency in our earth to divide; this, however, is overcome by the much more powerful attraction of the earth on its own parts, holding them together with an iron grasp. We have, however, evidence of this dividing force in the existence of the tides. The water, which is free to move, heaps itself up on the side of the earth facing the moon, and also similarly on the side away from it, thereby causing the earth as a whole to deviate in form from that of a sphere. This is owing to the difference of the attraction of the moon on different parts of the earth.

The cause of the tidal action is apparent when we consider that the nearer a body is to the moon the more it is attracted by it, and the variation in this force as the distance changes is expressed by saying that the force varies inversely as the square of the distance; for example, if we halve the distance the force becomes quadrupled, the inverse of one half being 2, which when squared equals 4. The water on the hemisphere towards the moon experiences greater attraction than the earth as a whole, and, being free to move, is therefore drawn away from the base of such hemisphere, and is heaped up under the moon in the form of a tidal wave; while on the other hemisphere the reverse action causes a similar wave on the opposite side to the moon. A tidal wave is produced by the sun's attraction in the same manner, but the solar tide is masked by the

greater lunar tide, and only serves to increase or diminish the latter according to the relative position of the sun and moon, as evidenced by the difference between spring and neap tides. This is because the sun is so much further off from us than the moon, and therefore the difference in its distance and also in its attraction on the two sides of the earth is small, when compared to the difference in distance of the two sides of the earth from the moon. In fact, the much larger mass of the sun does not nearly compensate in tide-raising power for its greater distance away.

The tidal action of the same body—in the case we are about to consider this body is the sun—varies inversely as the cube of the distance. We have given an example of the meaning of this expression where the square of the distance is involved, and this is similar to it; for example, if we halve the distance between the two bodies the tide-raising action becomes increased eight times, the inverse of one-half being 2, which when cubed ($2 \times 2 \times 2 = 8$) equals 8.

Now let us consider the effect of tidal action on a comet. First of all, comets with which we are familiar approach the sun much more closely than does the earth; secondly, the mass of the comet is so small that its attraction on its own parts is minute when compared to the control the earth has over its constituents; and thirdly, there are reasons for believing that instead of a comet having a single rigid nucleus, the latter consists of materials having just about as much adhesion to each other as have the separate stones in a heap of road-metal. The solid materials of a comet ought, therefore, to be drawn out into an elongated mass in its passage near the sun. Soon a limit of extension is

reached when the most extended parts are practically lost from the central control of the comet, and pursue their own dreary path each one in an orbit of its own, some going a little wider from the sun, and therefore slower than others, until after successive returns to the sun of the comet, there is along and about the original orbit, as it were, strewn the countless *débris* of the original aggregated mass.*

This breaking-up may take place under various forms, either in the mere dropping behind of straggling stones or in the separation of larger masses, each sufficient to produce to our sight the envelope of nebulous matter, and giving it the rank of a comet itself.

We now pass to the consideration of a matter which at first sight seems strange and astonishing. It is the close connection between comets and the falling stars, or meteorites, seen continually making streaks of light in the heavens on a clear night. Not that a meteorite is a comet, or a comet a meteorite, but from what has been said on the breaking up of comets we shall be able to understand that the straggling remains of comets may become what we see as falling stars when they get entangled in our atmosphere.

Let us now consider the observed appearances of meteorites from a cometary point of view. The phenomena of shooting or falling stars, meteors, meteorites, aërosiderites,

* In the case of a comet approaching the sun to within one-fiftieth of the earth's distance, and comets have gone much nearer than this, the tidal action becomes $50 \times 50 \times 50 = 125{,}000$ times what it is at our distance from the sun.

aërolites, aërosiderolites, bolides, and other bodies of a like nature, have been observed for ages. They have been called by various names, according to their size or according to their composition, but we will refer to the whole family of the smaller sort by the name of *meteorites*, while for the larger ones, seen at considerable intervals of time, and of sufficient brightness to call for remark in scientific periodicals, we will leave the name of *meteors*.

Meteorites are to be seen every fine night, and their frequency increases during the night, becoming most numerous just before daybreak; this is owing to the fact that during the morning hours the side of the earth on which we stand is turned in the direction in which the earth is moving in its orbit, so that the meteorites which are overtaken as well as those moving oppositely to the earth are seen at that time.

The great majority of meteorites are small, and on coming into our atmosphere produce sufficient friction to render them luminous and fuse them; the melted particles are left continually behind as an impalpable dust until the whole body is dissipated, unless, as in the case of the larger meteors which reach the earth's surface, the mass is sufficiently great to supply the enormous attrition of the surface, and yet leave the central portions unharmed. Of these multitudes exist in our museums, from a size little larger than dust to those which are measured in feet and weighed in tons.

They usually make their appearance at a height of about seventy-five miles, and disappear at a height of about fifty miles, and their average velocity is thirty miles a second.

Centuries back it has been observed that the frequency of meteorites increases at certain definite times of the year, notably on the 12th, 13th, and 14th of November, and on the 9th, 10th, and 11th of August; and in later times it has been further noticed that in certain years the display on these nights has enormously increased. For instance, in the years 1799, 1831, 1832, 1833, 1866, and 1867 there were brilliant displays, and older records tell us that a similar shower has occurred every third of a century. The period of this shower is thirty-three years, and the fall in 1866 was predicted and anxiously looked for. The night was favourable, and the number of meteorites observed was enormous; various counts were made at the different observatories, and numbers varying from 3,000 to 8,000 were reported. The shower was most brilliant during the half-hour preceding and following 1.15 a.m. on the 14th of November, when the number observed at Greenwich was at the rate of 120 per minute; by 4 a.m. the shower had ceased. Many instances were recorded in the daily papers of uneducated persons becoming alarmed by the fall of the stars, and coming to the conclusion that the end of all things was at hand. In the following year a display was again expected, and actually occurred, but was only partly seen in Europe just before sunrise. In America, however, it reached its greatest brilliancy at half-past four by Washington time, when the sun had already risen over England and the eastern hemisphere. This was only fair to our cousins over the water, for at the time we saw the display in the preceding year the position of America prevented them from participating in the sight.

In the following year the display had largely decreased, and until the year 1899, or possibly the previous one, we need look for no more than an ordinary shower.

Besides the observations made on the frequency or rate of fall, careful note was made of the direction in which the meteorites travelled, and a large number of the bright trains of light on the sky were transferred by the eye and pencil to a map. On continuing all these traces backwards, the lines were found to cross each other in a small space in the heavens in the constellation of Leo. From this small space, then, all the meteorites appeared to radiate, and the point in this space which most nearly represents the source of all the radiant lines is called the *radiant point* of the shower. The August shower differs from that of November in having no marked periodic maximum. Its appearance is pretty constant, but in some years an increase or decrease over the average has been recorded. In tracing backwards the streaks on the sky, we obtain a radiant point in the constellation of Perseus, not far from the star η Persei.

There are a considerable number of minor showers, each having its own radiant point, and the showers are recognised by the name of the constellation in which the radiant point is situated; thus the November meteorites are called the *Leonids*, those of August the *Perseids*, and those of December 12th the *Geminids*. It will be seen that of all the meteorites at any time observed, many, by their date of appearance and direction of motion, may be referred to some particular shower, while others cannot be so referred. Meteorites can therefore be divided into two classes, namely, *periodic* and *sporadic*.

Let us consider to what conclusion the foregoing periodic showers leads us. It is impossible to suppose that these frequently recurring showers are due to accident. They appear annually with great regularity, and are not

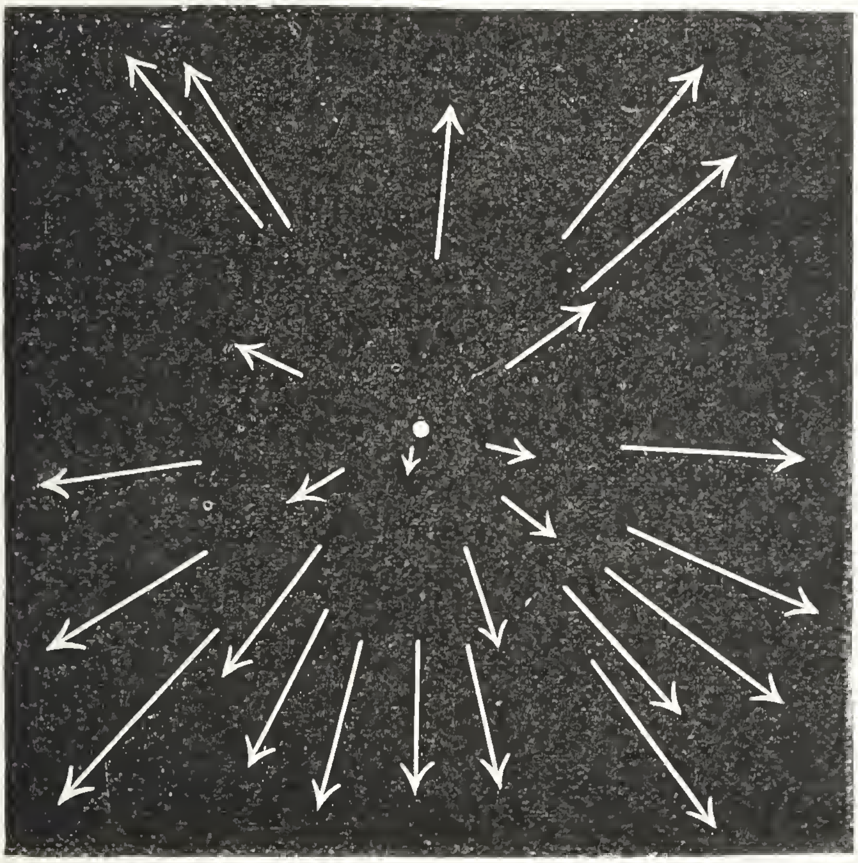

FIG. 3.—RADIANT POINT OF SHOOTING-STARS.

confined to any particular locality, a fact which points to their appearance depending on the position of the earth in its orbit, and leads us to the conclusion that at certain points in that orbit there exists a stream of meteorites crossing it, in their periodic revolution round the sun. On the width of the stream must depend the length of time over which the shower extends, and from the known

velocity of the earth the dimensions of the former can be calculated.

To test this hypothesis, let us consider what the appearances would be if the earth in its course plunged into a stream or cloud of meteorites. The direction pursued by the earth during the short period consumed in traversing the stream may be assumed to be constant; the same assumption may also be made with reference to the meteorites. The meteorites will therefore all have the same relative motion with reference to the earth, and the streaks of light marking their courses will be really parallel to each other. These, when viewed by a person at any part of the earth's surface, will appear to diverge from some source, and when prolonged backwards, will meet at a point common to all, and fixed in relation to the stellar vault.

This is exactly what happens in actual observation, and each particular shower has its own radiant point. The Leonids of November 12th—13th regularly appear, and it matters not on what part of the globe the observer is situated, nor at what time of night he sees the shower, still the bright streaks constantly emanate from the fixed radiant point. The same with the Geminids and Perseids.

If the breadth and density of the stream were constant, each successive passage through them would produce a similar shower each year, but if the meteorites revolve in flocks or clouds, and in periods not identical with the earth, the brilliancy of the successive displays will vary. This is observed to be the case notably in the Leonids, whose period of maximum fall is thirty-three years.

This periodicity was explained by Professor Newton by

assuming a ring of meteorites having some portion more dense than the rest, and of dimensions such that the bodies travelling on it performed their revolutions in 180, 185·4, 354·6, 376·6 days, or 33·25 years. The first two periods are, the one a little less and the other a little greater than half a year, and the next two, the one a little less and the other a little greater than a whole year, by such quantities that every thirty-three years the bodies in the ring have the same relative position to the earth. Professor Newton thought the orbit corresponding to the 354·6 days period the most probable, in which case the meteorites would make thirty-four revolutions in the same time that the earth makes thirty-three.

In 1867 Professor Adams attacked the problem, and for reasons which he then detailed, it seemed that the thirty-three years and a quarter orbit was most probable. In this case the cloud of bodies through which we pass comes round only once in thirty-three and a quarter years, and the ring is in the form of an elongated ellipse.

The orbits of many others of the showers have been of late years calculated, and from an examination of the figures representing the same, a more remarkable coincidence has been discovered.

Without going into the detail of the actual numbers representing the figure of the orbit of the Leonids, we may say that they bear a most remarkable resemblance to those representing the orbit of Comet I., 1866, discovered by Tempel, so much so that there is no doubt that the comet travels on the same orbit, and that there is some intimate relation between it and the meteorites.

If this were the only instance, it might be possible to consider it as a coincidence only, but M. Schiaparelli has shown that the orbit of the August meteorites, the Perseids, is closely related to that of Comet III., 1862, which was visible to the naked eye, and whose orbit was calculated by Oppolzer, of Vienna.

The orbit of the shower of April 20th also resembles that of Comet I., 1861. In 1868 Dr. Weiss pointed out the resemblance of the orbits of Biela's comet and the meteoric shower, formerly of the 6th and 7th of December, but now changed, as we shall see presently, to 27th November. On the return of Biela's comet in 1832, it was calculated to pass within 20,000 miles of the earth's orbit, at a point occupied by the earth on the 3rd December of that year. It so happened that the comet passed that point early in November, a month before the earth arrived there; we therefore missed the experience of a passage through part of the comet. If we had done so, doubtless a bright shower would have been seen, and Dr. Weiss gave a point in the constellation of Andromeda as that from whence the meteorites would have radiated. This agrees with the radiant point of meteor showers seen on December 7th, 1798, in which 400 were counted in a few hours, on December 7th, 1830, on December 6th, 1838, on December 6th, 1847, and on November 30th, 1867. It will be noticed that the shower gets earlier in later years, which means that the orbit of the meteorites is gradually altering, so that it cuts the plane of the earth's orbit near a point reached by the earth earlier each successive year. Now this is exactly what the orbit of Biela's comet was calculated to do: in 1772 it cut the

plane of the earth's orbit near the spot occupied by the earth on December 10th, while in 1852 the date became November 28th. In 1872, Biela's comet, if it still existed, would pass the earth's orbit about the end of August, and three months after, namely, on or about November 28th, we should pass the point of nearest approach of the two orbits. A close watch was therefore suggested to be kept for some days on either side of the 28th November, 1872.

On the evening of the 27th November all hopes were realised, for a grand shower was witnessed. The writer, together with the Rev. J. M. Wilson, counted them for some minutes at the rate of 2,500 per hour, while other observers gave much higher numbers. The shower commenced with the disappearance of daylight, and ended soon after 10 p.m., the maximum occurring about 6.45. It was noted that the streaks of light were faint, much more so than those of the great November shower of 1866.

It was thought by some that we had passed through Biela's comet, and M. Klinkerfues, of Göttingen, on November 30th, 1872, telegraphed to Mr. Pogson at Madras: "Biela touched earth on 27th; search near θ Centauri." A search was made and a comet found, but it seems highly improbable that it was Biela's comet that was seen, for it ought to have passed by some three months before. It has, however, not been seen as a comet since 1845. This is strong evidence of the conversion of a comet into meteorites. Again we have already pointed out that a flock of bodies travelling round the sun in an orbit would, owing to the lagging behind of those more distant from the sun, gradually become dispersed along the orbit, and eventually

form a ring of such bodies. If, therefore, a comet be, as we have already assumed, a flock of these bodies, there will be a ring formed from it of the same size and form as the orbit of the comet.

From the one original cloud there will exist all stages up to a perfect homogeneous ring. In the case of the November shower the cloud is still dense when compared with the ring, but in the case of that in August the difference has almost disappeared, and Schiaparelli has boldly said that the Comet No. III., 1862, is no other than the remains of the comet out of which the meteoric ring of the 10th August has been formed in the course of time, and that the denser portion of the ring—the comet, in fact—approaches near the earth once every 120 years, and is thus visible as a small comet. This meteoric ring, representing the cometary orbit, is 10,948 millions of miles in its greatest diameter, and it follows that, from our velocity of eighteen miles a second, and the length of time during which the shower lasts being some six hours, the thickness of the ring passed through is nearly four hundred thousand miles.

We have now discussed the various phenomena connected with comets in general, and will proceed to give a few details relating to particular comets. Firstly, we will take the known periodic comets.

Encke's Comet.

On November 26th, 1818, a small comet was discovered by Pons in the constellation of Pegasus, and remained visible for nearly seven weeks. Encke calculated the orbit of the body, and found it to be an elongated

ellipse, and assigned a period of three and a half years or thereabouts. The next thing was to look back in the records of former appearances of comets to discover whether such a comet had been seen before. This he did, and found that the observation of a comet by Mechain on January 17th, 1786, by Miss Caroline Herschell on November 7th, 1795, by Thulis on October 19th, 1805, were explained on the assumption of their being appearances of this particular comet, the intermediate seven returns having been missed, and that the comet had a period of three and one-eighth years.

The next thing was to calculate its next return, and Encke foretold it would arrive at its perihelion on May 24th, 1822. On June 2nd of that year it was again seen, according to the prediction, and it is now a well-recognised member of our system. A curious fact in relation to this comet is that at the time of its first few returns its period was 1,212½ days, whereas of late years the period has been become reduced to 1,210½ days, and this decrease has been gradual, each successive revolution taking a shorter time than each preceding one. This fact points to a reduction in the size of the orbit, and might be occasioned by a medium resisting the comet's motion in its passage through it. It is not, however, conclusive evidence of the existence of such a medium, for other similar comets do not appear to experience such a resistance.

Another point to note is that this comet has been observed to contract in bulk on approaching to, and to expand on receding from, the sun. This may be due to a change from visible cloud to invisible vapour effected by the sun's heat, and the reverse by cold on receding.

Encke's comet has little or no tail, and is not a brilliant object by any means, but it is noted as being the first comet of short period discovered. It returned in the autumn of 1881, when Mr. Common re-discovered it on the 27th of August, and it was visible to the naked eye at the end of October; and it again appeared in January of the present year, 1885. Its greatest distance from the sun is 387,000,000 miles, and its least distance 32,000,000.

Winnecke's Comet.

On June 12th, 1819, M. Pons observed this comet. Its orbit was calculated by Encke, who assigned a period of 5½ years. On March 8th, 1858, Winnecke discovered a comet which he soon observed to be identical with the one discovered by Pons, and is now a recognised member of our system, having a period of 5·54 years. It was re-discovered the last time on Feb. 1st, 1875, and it passed its perihelion on March 11th of that year. On Dec. 4th, 1880, it was predicted to pass its perihelion again, but it was expected to be so faint as to escape notice, and it does not appear to have been seen.

Brorsen's Comet.

This comet was discovered by M. Brorsen on Feb. 26th, 1846, and its orbit was calculated by Mr. Hind. Its next arrival at perihelion was predicted for Sept. 26th, 1851, but its position was unfavourable for observation, and it was missed. On March 18th, 1857, it was again seen, and also on its subsequent returns, the last time of its re-discovery being in March, 1879. It passed its perihelion again in September, 1884, but, owing probably to its apparent

proximity to the sun, was not seen. Its period is 5·58 years. When at its greatest distance from the sun, it is 537,000,000 miles away, and when at its least, 64,000,000 miles.

Tempel's Comets.

M. Tempel has discovered three comets which have turned out to be periodic. First, there is a comet discovered by him on April 3rd, 1867, which remained visible for sixteen weeks, and passed its perihelion on the 24th of May of that year. On April 3rd, 1873, it again appeared, and was re-discovered by M. Stephan. It also appeared again in 1879, passing its perihelion on the 7th of May. Its period is, therefore, eight days short of six years, and therefore, if unaffected by planetary attraction, it would return again to perihelion at the end of April, 1885. M. Gautier, however, calculates that owing to the perturbing action of Jupiter its return to perihelion will be delayed for 148 days, namely, to the end of September.

Secondly, a comet was discovered by M. Tempel on July 3rd, 1873, it having passed its perihelion on the 25th of June of the same year. On the 7th of Sept., 1878, it again passed its perihelion; its period, therefore, is five years and six weeks. In October, 1883, it ought to have been seen again, and M. Schulhof issued an ephemeris, showing its probable daily place for some weeks, but it does not seem to have been observed.

Thirdly, on the 27th of Nov., 1869, M. Tempel discovered another comet, and on the 10th of October, 1880, Prof. Swift, of Rochester, N.Y., re-discovered what, from a comparison of the two orbits, is probably the same body,

and it has since been frequently referred to as Swift's comet. It passed its perihelion on the 8th of November following. From its orbit a period of $5\frac{1}{2}$ years was assigned by MM. Schulhof and Bossert, and also by Mr. Chandler, as the most probable one; but an eleven-year period is possible; in case the former is correct, it was missed in 1875. In 1886 it ought to return, but its position will be unfavourable for observation.

Biela's Comet.

We have already said so much in relation to this most remarkable comet that little more need be added here. It was observed by M. Biela on Feb. 27, 1826, and was visible for eight weeks, and the orbit calculated by Santini, who assigned a period of $6\frac{1}{2}$ years. On examining the records, it was identified with a comet appearing on March 8, 1772, discovered by Montaigne, and with that seen by Pons on Nov. 10, 1805. Its next return to perihelion was fixed for Nov. 27, 1832, and Olbers pointed out that it would then pass within 20,000 miles of the earth's orbit, but as the earth would not reach the point approached by the comet until a month after the latter has passed, there need be no fear of collision. The comet returned as predicted. In 1839, its next return, it was unfavourably situated for observation, being close to the sun. In 1845 it was again seen, when, as we have already observed, it divided into two parts. In 1852 the two comets were travelling side by side, and from that time they have not been seen again. Whether they existed in 1859 we know not, for their position would have been too near the sun for observation.

They ought to have appeared in 1865 or 1866 but were not seen, and Biela's comet or comets can now scarcely be said to belong to the family of periodic comets. The aphelion and perihelion distances of this comet were 585,000,000 and 82,000,000 miles respectively.

D'Arrest's Comet.

This comet was discovered by D'Arrest on June 27, 1851. From the form of its calculated orbit its return was predicted for the end of 1857 or beginning of 1858, when it returned to view. On its subsequent returns, it has again been seen, and was found by M. Coggia on its last return on July 9, 1877. The period is $6\frac{1}{2}$ years, and it was expected again to appear towards the end of 1883, but it is an extremely faint object, and appears to have been missed.

Faye's Comet.

M. Faye discovered this comet on Nov. 22, 1843. Le Verrier calculated its orbit, and its return was predicted for the early part of 1851. On Nov. 28, 1850, it was again seen by Prof. Challis at Cambridge, and it has been also seen several times since. Its period was 7·44 years, but Jupiter so perturbed it in 1875 that from this cause and others its period was lengthened by 56 days, and the last time it appeared was on August 2, 1880, passing its perihelion on Jan. 22, 1881, it may therefore be looked for towards the end of 1887 or beginning of 1888. The aphelion and perihelion distances of this comet are 603,000,000 and 192,000,000 miles.

Denning's Comet.

Mr. W. F. Denning, of Bristol, discovered a comet on Oct. 4, 1881, and from the orbit calculated by M. Schulhof a period of $7\frac{3}{4}$ years was assigned. It passed its perihelion on the 13th of Sept. From a later investigation of the orbit of this comet by Mr. W. E. Plummer he obtains a period of nearly 9 years. He calls attention to the interest in this comet from the fact that its period holds a mean position between the family of comets having a period not far removed from 5 years, and whose greatest distances from the sun are about that of Jupiter; and the next comet described, called Tuttle's comet, with a period of $13\frac{1}{2}$ years and a maximum distance equal to that of Saturn.

Tuttle's Comet.

On Jan. 4, 1858, Mr. Tuttle, at the Harvard College Observatory, found a comet which turned out to be the same as that discovered on Jan. 9, 1790, by Mécham, who then calculated its orbit. It returned in Nov., 1871, and is again expected to put in an appearance in July, 1885, having a period of 13·66 years.

Pons' Comet.

We now pass to the comets of longer period, and it should here be noticed that after leaving the comets of short period there is great break until we get to a batch of comets having a period of from 67 to 77 years. Of these mention should be made of Pons' comet, discovered by him in 1812, and whose return to perihelion was predicted for

1884. Return sure enough it did, and on Sept. 2, 1883, Mr. Brooks re-discovered it some seven months earlier than it was predicted, but considering the length of its period this is no large error. On Jan. 15, 1884, it reached its maximum brightness when it was visible to the naked eye over the western horizon as a faint object with a tail about 1° long. Its period as determined by MM. Schulhof and Bossert is 71·48 years.

Halley's Comet.

The most remarkable of long period comets is that called after Halley. In 1682 there appeared his large comet having a tail 30° in length, when in its maximum splendour. Newton had, a short time previously, been applying his laws of gravitation to the planets, and had suggested putting them to the test by the calculation of cometary orbits on their basis. Halley calculated the orbit of this comet, and was led to conclude its identity with the comets of the years 1531 and 1607, whose orbits he also calculated. On these grounds he predicted its return in 1759. The effect of the attraction of Jupiter and Saturn on the date of its reappearance was calculated by Clairaut, who concluded that Saturn would retard its reappearance by 100 days, and Jupiter by 518, bringing the probable date of reappearance to the middle of April, 1759. On the 12th March, 1759, it was observed, thereby verifying the laws of gravitation in a most complete manner. The next return to perihelion was predicted to take place by several calculators on dates varying from the 4th to the 26th of November, 1835, and on the 5th of August in that year it was

discovered as a very faint object; it increased in brightness and passed its perihelion on November 16, 1835, close to its predicted time. In the year 1911, those of us who are then alive may hope to see this well-known comet. It recedes from the sun to the enormous aphelion distance of 3,200,000,000 miles, and approaches to within 56,000,000 miles when in perihelion, taking more than seventy-six years to complete its revolution round the sun.

It was not until October 10th in the year of its last appearance that any tail was developed. On that day the nucleus became suddenly brighter, and a luminous jet was thrown out towards the sun; six days later another jet was thrown out with more violence, and other jets of various forms were emitted during the whole period that the tail was visible. These jets were wafted backwards and eventually formed the tail of the comet.

Two months after passing its perihelion it was again visible, and then, curiously enough, it had lost its tail, and appeared to the unaided eye as a hazy star of about the fourth or fifth magnitude. This comet has been identified with apparitions of large comets since the year 11 B.C., about eighteen such occurrences being probably due to successive returns of Halley's comet. The apparition of a comet in 1066, which was thought to be the forerunner of the victory of William of Normandy, was in all probability the same comet.

Of other comets of very long periods or doubtfully periodic, we should notice that of 1680, the large comet that set Newton thinking of the application of his laws to those bodies which resulted in Halley's prediction of the return of his comet. The tail of this comet reached the

enormous length of 60,000,000 of miles just after passing its perihelion, and was emitted from the head in the short period of two days; at a later date the tail extended to 120,000,000 of miles, one-third as far again as the distance from the earth to the sun. In passing its perihelion it was so near the sun that Newton calculated its temperature to be 2,000 times that of red-hot iron. Its period has been given as 8,814 years.

The comet of 1811 was an important one. Its length, measured on the heavens, was 25°, representing in actual distance 100,000,000 of miles, with a maximum breadth of 15,000,000 of miles. The head measured 112,000 miles in diameter and the nucleus 428 miles. According to Argelander, its period is 3,065 years, and its greatest distance from the sun 40,121 millions of miles.

The great comet of 1843 was probably the most brilliant object of this century, not only was the nucleus but part of the tail visible in full daylight. It appeared suddenly to observers in the northern hemisphere about the middle of March, having been visible for three weeks previously in the southern hemisphere. The tail of this comet occupied the enormous length in the heavens of from 40° to 45°, and the comet is remarkable in having passed extremely close to the sun, the distance being only 538,000 miles from its centre. The diameter of the sun is about 880,000 and its radius 440,000 miles; the comet therefore, was only 98,000 miles from the surface of the sun, and the heat experienced must have been enormous. Owing to this proximity the comet proceeded at a great velocity both in space and in angle round the sun, and in

one day the imaginary line joining it with the sun moved through 292°. Its period is about 2,000 years.

Donati's comet of 1858 will be remembered by many of our readers. It was first seen by Dr. Donati in June of that year, as a faint nebulosity only, when some 240,000,000 of miles from us. On August 20 a tail began to appear, and shortly afterwards it became visible to the naked eye, and remained so in this hemisphere until the end of October, after which it was seen in the southern hemisphere until March 4, 1859. The actual length of the tail at this time (October) was 33,000,000 of miles.

In 1861 there appeared a comet which attracted public attention more than others have done. Mr. Tebbutt, of New South Wales, discovered the comet on 13th of May, but it was not until June 29 that it was visible in this hemisphere, when it was taken for the moon rising. Sir John Herschell says that its light that evening far surpassed that of any planet, except perhaps Venus at her maximum, and it far exceeded any other comet he had observed, even those of 1811 and 1858. The tail extended from a point 8° or 10° above the horizon, to within 10° or 12° of the pole star, or about 30°, and on the 2nd of June it had increased to more than 72°. On Sunday, June 30, Mr. Hind thought it probable that the earth passed through the tail of this comet, for it had passed through the plane of the earth's orbit at 6 p.m. on June 28, at a distance of 13,600,000 miles nearer the sun than the path of the earth. On the Sunday, the 30th, at 10 p.m., the earth arrived at that point of its orbit in line with the sun and the point of passage of the head of the comet

through the above-mentioned plane; and judging from the curvature of the tail, and the lagging behind of the particles composing it, Mr. Hind thought it probable that the earth passed through it in the early part of Sunday, or at any rate through a part of space recently swept over by the tail. A peculiar phosphorescence was observed in the sky that evening, and was noticed by many persons as an unusual phenomenon. Mr. Lowe noticed a yellow auroral glare-like look, and the sun, though shining, gave but feeble light, and the comet was visible at 7.45 p.m. during sunshine. He adds that the candles were lighted in the parish church at 7 p.m., a fact which shows that a sensation of darkness was felt before sunset. That these phenomena were observed there is no doubt, but that the comet was the cause is not so certain, for we can scarcely reconcile the obstruction of the sun's rays, with the remarkable transparency of comet's tails in allowing stars to be seen through them without reduction of their brilliancy.

The comet of 1862 (III.) is remarkable and interesting on account of the jet of light which was seen during a considerable time to proceed from the nucleus. This jet issued from the side towards the sun, and changed its form and position with great rapidity.

The comet discovered by Coggia at Marseilles on April 17, 1874, and called after him, is remarkable from its having had for some time two eccentric envelopes of light, giving the head an unusual appearance. Mr. Hind calculated the tail to have increased from four million miles in length on July 3 to twenty-five millions on July 19.

In angular measure the increase was from 4° to 43° or more. Its period is put at four thousand years, and it

FIG. 4.—TELESCOPIC VIEW OF THE NUCLEUS OF COGGIA'S COMET, JULY 12, 1874.

must recede from the sun to a distance of some four hundred times that of the earth from it.

The comet of the autumn of 1882 was an impressive object when seen at the end of September in the south-

eastern sky. Well could we imagine, while gazing on it, the awe and bewilderment with which our forefathers would have looked upon such a portent. Besides being simply a large comet, its history is worthy of some slight comment for other reasons, and in one point at least it is unique.

This comet was first seen by Mr. Findlay, the First Assistant at the Observatory at the Cape of Good Hope, on the morning of September 8. He was attracted into his garden by the marvellous brilliancy of the stars, and he says that on turning his eyes eastward he detected the stranger at once; it did not appear as a comet, but he knew there ought not to be any large star in the spot occupied. It was about midway between Alpherat and Regulus. He called to his daughter, and asked her to put her head out of the window, when she at once said, "A comet!" It was seen at Melbourne on September 10, at 5 a.m., and remained visible to within a minute of sunrise. On September 11 it remained visible after sunrise, and appeared to have a tail from three to four degrees in length. On the morning of September 12 this comet was discovered by G. W. Cruls, at Rio de Janeiro, and this was the first observation of which we in this country got intimation, hence it was called Cruls' comet. Mr. Common, at Ealing, discovered a comet while observing the sun at 11.45 on the morning of September 17; it was then close to the sun, on the west side of the same; he watched it get nearer until 12.6, when clouds came on, and the comet was 13′ 45″ only from the sun, less than one-half the diameter of the latter body. Mr. Findlay and Dr. Elkin

were more fortunate; they actually watched the comet pass on to the sun's disc and disappear at $4^{h.}$ $50^{m.}$ 58^{s} Cape mean time. We should have expected it to appear as a dark object in comparison with the intensely bright sun when viewed under such circumstances; strange to say, it was quite invisible. Now, the central portions of the sun are much brighter than the rest, so that if the comet's disappearance was due to its brightness being equal to that part of the sun close to where it was viewed at one time, at another time it must have appeared either brighter or less bright than other parts of the sun's disc; since this was not so, we can only assume that the comet was of such tenuity that the sun's light passed through it to us without appreciable loss. The heat experienced by the comet at this time was immense, for it was probably only about 1,600,000 miles from the sun's surface, and at perihelion, which happened on the same day about 5 p.m., it would be still closer—namely, 716,200 miles from its centre, and 285,500 from its surface. Dr. Morrison calculates that the velocity of the comet at perihelion was 295·36 miles per second, while, at aphelion, when 160 times our distance or 5½ times that of Neptune from the sun its velocity will be only 75 feet per second. The comet was next seen on the 18th, on the west side again, having in a few hours completed more than 180° of its orbit, and having travelled in the interval at the enormous velocity just mentioned. From its first observation by Mr. Tebbutt at Windsor, New South Wales, until May 26, 1883, an interval of about 260 days, the comet described more than 340° of its orbit, leaving the remaining 20° to be done in

three times as many years; such is the enormous variation in angular velocity. Its motion from the sun was contrary to that of the planets, or, as it is called, retrograde. On the 22nd the comet was examined with the spectroscope, and, besides the ordinary continuous spectrum from the nucleus and the hydro-carbon spectrum from the coma, there appeared the two D lines and others crossing the field, giving unmistakable evidence of the presence of the metal sodium in some form or other.

Speculation was rife as to whether this comet had been seen before. Its orbit appeared very like those of the comets of 1843 and 1880, and it was put forth as probable that the first of those comets experienced so much resistance in passing through portions of the lighter solar gases extending far beyond the sun as we see it, of which the solar corona gives evidence, that its period had been reduced to 37 years, and it had therefore reappeared in 1880; and further, that the resistance experienced in 1880 had reduced the 37 years period to one of a little over two years. It was also added that the further resistance of the 1882 perihelion passage would cause the comet to return again early in 1883, to eventually fall into the sun and disappear for ever. This has been found not to be the case, and, although various periods, varying from 269 to 1,376 years, have been assigned according to the observations used in the calculation, it seems that an orbit having a period of from 700 to 800 years is the most probable one, so we may conclude that the comet has not been before seen during historic times. On receding from the sun the apparent length of the tail increased from 10° on October 1st to 23°

on November 5th, but the apparent proximity to the sun affected the visibility considerably; and the estimates of the length at different times are various. Assuming the angular length on the 6th of November to have been 23°, we can estimate the actual length roughly, for the comet was then at about an equal distance from the earth and sun, namely 135 millions of miles, and the earth was distant from the sun say 90 millions of miles; further we may assume the tail to be in a direction opposite to the sun. Having these data it is easy to calculate how long the tail must be in order to subtend the above angle, this will be found to be about 200 millions of miles as the approximate length. Another curious matter requires our notice: after passing its perihelion, the brightest part of the comet, and what was taken to be the nucleus when using moderate telescopes, began to elongate in the direction of the tail, and by the 10th of October it appeared as an oval patch of light nine times as long as it was broad. On examining the comet with the 26-inch equatorial at Washington on November 5th, there appeared a circular nucleus near the centre of the oval patch, with two other smaller condensations of light or nuclei following it. The nucleus proper was, however, circular, while the other two were irregular in shape and much less bright. On November 6th these nuclei were much more pronounced. It seems possible that we have here an instance of the breaking up of the nucleus of a comet, each portion to become, if sufficiently large, a new comet; or should a more minute division take place, then a flock of meteorites will be the result.

CAVES.

By James Dallas, F.L.S., *Curator of the Albert Memorial Museum, Exeter.*

There is something connected with the name of a cave which calls up all sorts of strange and weird associations in the mind. This is, perhaps, in part due to our unfamiliarity with caves of any size, for though in certain parts of England they are sufficiently plentiful, yet it does not fall to the lot of every one to visit a cave district; and the vastness, the gloom, and the grotesque surroundings which we are apt to attribute to these natural excavations are, therefore, the result, not of experience, but of imagination. And the imagination is doubtless unwittingly influenced by the tales and stories of our youth, in which all kinds of impossible horrors, and of equally impossible charms, are connected in some mysterious manner with vast subterranean chambers, pregnant with palpable darkness or glittering with gems, and brilliantly illuminated, we know not how. We picture to ourselves the horrors of the den, which to the youthful imagination naturally becomes a vast gloomy cavern, whence the giant Slaygood sallies forth to waylay Bunyan's much-harassed Christian; or we invest with all sorts of magic beauties the wonderful underground apartments to which we are introduced in the fascinating pages of the "Arabian Nights." Most of us probably have hazy reminiscences of wonderful smugglers' caves and desert island caverns, the scenes of endless improbable adventures

and of hair-breadth escapes, while the gloomy sea-shore refuge of Sir Walter Scott's famous smuggler, Dirk Hatteraick is as well known to us as are our most familiar surroundings.

Nor is it only in works of fiction that allusions to caves and caverns are to be found. When King David fled in fear from Achish, King of Gath, he took up his abode in the cave of Adullam, where he was joined by four hundred followers, and it was in a cave at Engedi that he secreted himself when pursued by Saul. The five kings of the Amorites, after their defeat by Joshua, took refuge in a cave at Makkedah, whence they were brought out by the Israelites and hanged upon five trees, after which their bodies were re-consigned to the cave, and the entrance was blocked with stones, thus affording a historic instance of cavern-sepulture concerning which more will be said hereafter.

In ancient Greek and Roman mythology, too, are to be found constant references to caves and underground habitations. If there was any idea at all of the nature of Hades, it was probably regarded as a huge subterranean vault or abyss, while many of the mythical gods, sibyls, and nymphs of the Romans were supposed to have their abodes in the interior of the earth, in caverns amongst the rocks or mountains. The Greek worship of Bacchus, Pan, Pluto, and the Moon, as well as the delivery of oracles at Delphi, were conducted within caves in the earth, while in Persia some connection seems to have existed between caves or caverns and the ancient worship of Mithras, the "Light-God" of the Arian races.

If by the ancients it was believed that supernatural beings were associated with the mysterious and awe-inspiring depths of subterranean caverns, their successors were certainly in no way behind them in attributing to these inexplicable excavations a similar unearthly association. In France and Germany the terms fairy, dragons' and devils' caves sufficiently denote the origin attributed to them in mediæval times; and until very recently, if not even in some places to the present day, caverns have been regarded by the rude and superstitious peasantry as the dwellings of evil spirits, fairies, and "Brownies," whose mischievous or benignant interference in the affairs of men forms so prominent a feature in the quaint nursery stories of Teutonic lands. One such story or legend is quoted by Mr. Boyd Dawkins, as having still been current as late as the middle of the last century, near Elbingrode, in the Hartz district. When preparations were being made for a wedding breakfast (so runs the legend), the friends of the bride and bridegroom proceeded to the neighbouring caves, and demanded from the dwarfs who were supposed to inhabit them copper and brass kettles, pewter dishes and plates, and other kitchen utensils. "Then they retired a little, and when they came back, found everything they desired set ready for them at the mouth of the cave. When the wedding was over, they returned what they had borrowed, and, in token of gratitude, offered some meat to their benefactors." Nor are stories of fairies and dwarfs, remnants probably of ancient pagan beliefs, the only ones attaching to caverns in the earth. Amongst the peasants of the hills of Granada it is still related, and perhaps half believed, that Boabdil, the last

Moorish King of Granada, who was dethroned by Ferdinand and Isabella in 1492, now lies concealed in the caves of the mountains, and will, upon the entry of some rash mortal, be awakened from his torpor, and with his sleeping army revive in Spain the long extinct supremacy of the Moors.

More authentic accounts of the use of caves as places of refuge are not wanting. Cæsar has related how the Aquitani, hard pressed by the well-trained legions of Rome, fled to the caverns of Auvergne, where they hoped to conceal themselves from the dreaded enemy; while quite recently, in 1845, five hundred Arabs betook themselves to a cave at Khartain, in Algiers, and, refusing to surrender themselves to the French, were suffocated by smoke, produced by the ignition of a mass of brushwood and other inflammable material at the mouth of the cave—an act of barbarity which has generally been attributed to the orders of Marshal Pelissier, afterwards governor of Algiers.

Interesting, however, as are many of the facts and legends connected with caves in almost all parts of the world, it is not to these that we wish specially to refer, for in fact still more interest attaches to the physical and zoological aspects of the subject, and to the light which is thus indirectly thrown upon the customs and affinities of the early races of mankind.

We are, perhaps, generally disposed to associate the formation of caves with the action of the waves upon a rocky shore, and certainly some of the most remarkable caves are due to this cause. The process of attrition can indeed often be observed in actual progress, and those who

have seen the gigantic waves break upon a rock-bound coast, and have observed the huge masses of stone, which have been torn away like so many fragments of timber and strewn upon the beach, can form some tolerably accurate idea of the power of the sea to eat its way into the face of any cliff, when once it has found a weak place in the rock. In the beautifully columnar basalt cliffs of the west of Scotland such a cave has been hollowed out by the fury of the Atlantic storms, and we are all familiar with the name at least of Staffa. Off the coast of Ireland is a similar and equally familiar cavern known as Fingal's Cave, which is also due to the action of the waves. These sea-worn caves are easily distinguished from those formed by other agencies. They are seldom of great extent, and they generally lie in a tolerably horizontal plane. Sometimes they lie far above the present water line, but the nearly level floor, the indication in their vicinity of an ancient beach, and the fact that in many cases at least similar caves of greater or less extent are to be observed opening on the same general horizon, prove conclusively that they must be due to the prolonged beating of the ocean waves upon a rocky shore. From the nature of their origin, it follows that these caves can seldom have been used as places of refuge or habitation either by man or beast; for even when the water no longer fills them at high tide or during violent storms, they are generally placed in positions almost impossible of access. It is not, therefore, strange that they present few marks of special interest to the naturalist, the anthropologist, or the geologist, though, indeed, their existence above the present level of

the sea affords valuable and conclusive evidence of a rise in level of the land surface in their vicinity.

Caves are occasionally due to volcanic action, being sometimes produced by the expansion of steam and gases within a mass of molten lava, while in other cases they have been formed by the passage of lava streams over the surface of snow and ice, the subsequent melting of which of course leaves a hollow space or cavern. The cracks produced by violent earthquakes have also sometimes originated caves of greater or less extent, but the caverns which have the greatest charm for the student of science are those which have been eaten out of the solid rock by the gradual and imperceptible action of fresh water.

Perhaps the most familiar examples of caves thus produced are the hollows and excavations so frequently to be seen at the bases of inland cliffs. These are sometimes the result merely of atmospheric influences—frost, rain, and sunshine. Should the beds at the foot of a cliff chance to be of a softer material than the overlying rocks, they would naturally "weather" away more rapidly; but often the process of attrition is aided by a stream of water running at the base of the cliff, when hard and compact rocks would be readily worn away. The stupendous effects of prolonged weather action alone are, however, remarkably exemplified in the rock-shelters of the cliffs of New Mexico, Colorado, and the adjacent territory in the United States, where the mysterious cliff-dwellers made their abode.

Besides these surface caves there occur, however, others of greater dimensions, which penetrate into the very heart

FIG. 1.—INTERIOR OF FINGAL'S CAVE.

of the rock. When such caves are found in pure sandstone rocks, they are the result solely of mechanical action. The rain water, falling upon the surface, gradually finds its way between the cracks or joints in the solid rock, and in passing through, slowly wears away a cavity, which increases in size with varying rapidity, according to the nature of the stone it traverses. Sometimes the trickling water meets with a bed of softer and less compact material than the rest, and then true caves, and not mere vertical fissures, are the result. Such caves are of not unfrequent occurrence in the hard quartzose sandstones known as Millstone grit, which occur beneath the coal measures in Derbyshire and Yorkshire, as well as in other coal basins of this country. An excellent and well-known example is the cavern known as the Kinderscout in Yorkshire, and similar excavations occur in sandstone rocks in many parts of the world. In the Tertiary sandstones near Paris, these water-worn caves have been discovered, containing the bones of extinct animals; and in Australia, though the explorations which have hitherto been undertaken have been of the most imperfect kind, the remains of animals have also been obtained from sandstone caves, while some most remarkable paintings, of very uncertain origin, have been observed in some of them.

But the interest attaching to these caverns or excavations dwindles into insignificance when we come to examine the vast subterranean vaults to be met with in the calcareous or limestone rocks. The great extent, the gloom and grandeur, and the beauty of these natural caves can hardly be exaggerated in even the most glowing de-

scriptions, and it is scarcely to be wondered that all kinds of superstitious fancies should have been connected with them by the uneducated peoples of Europe and Asia. None but the boldest or most reckless of men would formerly enter their dark and chilly precincts, and they were consequently supposed to be more vast in extent than is even the case. Yet these extraordinary excavations were due not to any dread supernatural power, nor to any great convulsions of nature, but were the result of the gradual disintegration and wearing away of the solid rock by the mechanical action of running water, combined with the even more active influence of chemical decomposition.

The limestone rocks in which these vast caverns occur are to be met with in all parts of the earth, and owe their origin, for the most part, to the accumulation of organic remains on the bed of a no longer existing ocean. The shells of mollusks, and of those minute gelatinous creatures to which the name of Foraminifera has been applied, are doubtless the chief, if not the only, source of this enormous mass of carbonate of lime, and indeed some rocks, such as chalk, are almost entirely composed of the minute and beautifully formed calcareous shells of Foraminifera.

It was at no very distant date pretty generally believed that caves were due to internal contortions of the crust of the earth, by which the rocks were rent asunder, leaving gaps and breaks such as we now see. But an examination of the interior of the caves soon showed that this was quite an impossible explanation, for it was found that both the floor and the roof were composed of solid rock, and that, so far from there being any indication of folding and crumb-

ling of the mass, which could account for the existence of a cavity, the rock was in fact unbroken both above and below, and in most cases the lie of the beds was perfectly continuous. Then, again, it was supposed that the caves had been worn by the mechanical action of running water alone, in places where a fault occurred in the rock—that is, where, from a local displacement of the beds, one portion of the series was elevated above or depressed below its normal level, thus leaving a vertical or diagonal crack, which might well be supposed to be a line of weakness. Probable as this view appears, it was, however, found that the caves did not in fact follow these lines, but were sometimes seen actually to be excavated across them, and yet another theory was necessary to elucidate their origin.

It has of course been observed by every one familiar with sedimentary rock quarries of whatever kind, that the stone displays not alone parallel lines indicating the successive layers or beds of stratification, but also a series of irregular, and more or less broken lines, running in a direction to some extent vertical to the planes of stratification. These lines or cracks, without which it is difficult to conceive how quarrying operations would be possible, are technically known as joints, and it was found that water-worn rock fissures were in general to be traced to these cracks. The rain water falling upon the surface of the earth would of course naturally flow into any hollows, however shallow, which happened to exist upon the general surface of the rock; and when it chanced that a "joint" or fissure occurred within the area of the hollow, the water would gradually find its way downwards. The

power of running water alone in wearing away solid rock is well known, but the water thus finding its way from the surface would also bear with it minute grains of sand, and these would aid in the attrition of the limestone over the exposed faces of which they were carried along. Neither water nor sand, however, of themselves would be sufficient to account for all the phenomena of cave formation; and, indeed, it may be affirmed that alone they would be quite inadequate to produce the extraordinary results observable in some caverns. We must, then, seek some other, and even more powerful, agent to account for the existence of such gigantic excavations as the Victoria Caves in Yorkshire, and the still vaster caverns of Kentucky and other regions of America. This agent is carbonic acid.

A large quantity of free carbonic acid exists in our atmosphere. It is given off from the lungs of every living creature, and in far larger quantities it is generated by the decomposition of animal and vegetable matter. In forest tracts, such as we may suppose all the cave regions to have been at the time when the formation of caves was in most active operation, the land must have been constantly strewn with leaves, branches, and other vegetable refuse in a perpetual state of decay, and hence there would be a large accumulation of carbonic acid in and above the surface soil. While thus floating about in a perfectly free condition, it would of course possess little power to act the part of nature's quarryman; but it happens that water has the power of gathering up into its volume a large quantity of carbonic acid, and thus the rain falling through the

atmosphere and percolating the loose surface soil would gradually accumulate a large amount of this free acid, and bear it whithersoever it went. The principal ingredient of the ordinary limestone rocks is pure carbonate of lime, and this is quite insoluble in ordinary water. But any fluid containing carbonic acid has immense power in dissolving this substance; and even if it could not be proved, we might with great certainty affirm that the carbonic acid contained in rain water must be an important factor in the decomposition of limestone, and the consequent formation of caves. Fortunately, however, facts, which are ever more acceptable than theory, are not wanting to support this assertion.

There is to be found in the Doveholes in Derbyshire a small cavity, where, in the line of a joint, the carbonic acid has attacked the limestone, and gradually eaten it away in fantastic patterns such as could not possibly have been produced by running water alone. From the sides of the main channel of the excavation are to be seen irregular honeycombed hollows, running upwards, downwards, and, in fact, at every angle from the line of the joint, which are to be attributed solely to the chemical action of the carbonic acid upon the carbonate of lime. The surfaces are worn into sharp points and angles, such as we see on a small scale when a piece of sugar is gradually dissolved by water, while minute fossils, formed of a harder and less soluble material, are left standing out in bold relief when the softer limestone about them is eaten away.

Often the surface of a limestone country also affords

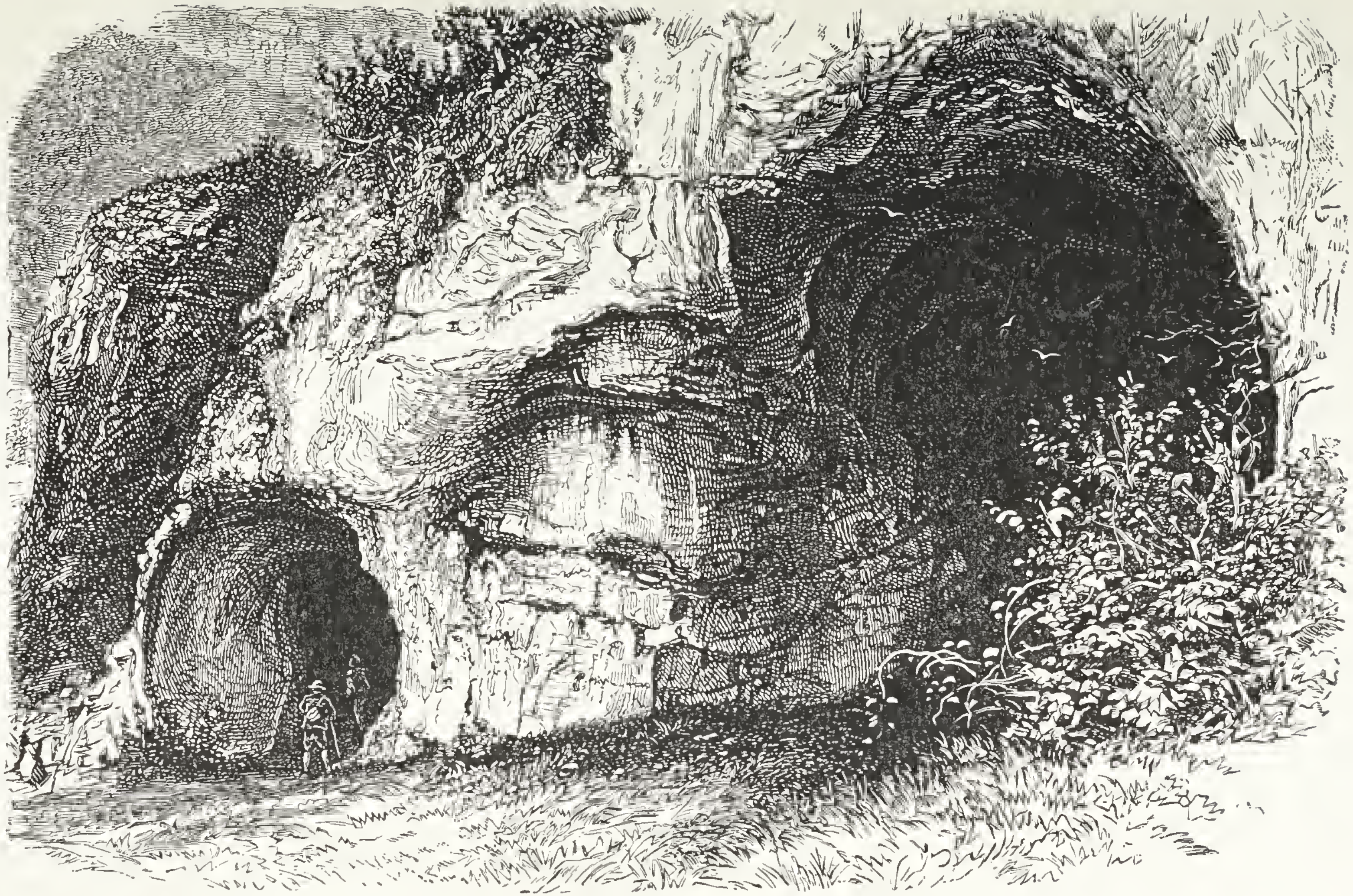

Fig. 2.—THE DOVEHOLES, DOVE DALE.

striking evidence of the action of carbonic acid on the solid rock. In Yorkshire, the result of this action is most strikingly exhibited near Ingleborough, where the rain water, attacking the exposed limestone in the lines of joint, has gradually eaten away the solid rock, so that the whole surface is covered with chasms of varying depth. As the joints, for the most part, cross one another at right angles, the masses of stone standing above these chasms are approximately rectangular in form, and stand in a position of complete isolation from each other, while in some cases the effect of the acid contained in the water has been such that they are also detached from the underlying rock, and thus become transformed into "rocking stones." It is from facts such as these that geologists have been enabled to arrive at a satisfactory conclusion as to the mode of formation of caves in limestone rocks; but there is yet another piece of evidence, which should not be passed over, to be found in the enormous quantity of carbonate of lime borne in solution by running streams, which have during a part of their course passed through limestone rocks. Mr. Prestwich has estimated that the mean discharge of the Thames at Kingston is 1,250,000,000 gallons, and that each gallon contains on an average about nineteen grains of salts held in solution, so that in every twenty-four hours no less than 3,364,286 pounds, or 1,500 tons, of mineral matter is carried down the river, and of this no less than about 1,000 tons consists of carbonate of lime. This gives us an idea of the power of rain water in dissolving limestone rocks, but the amount of carbonate of lime absorbed by the water which slowly percolates through cracks and fissures, coming in its

progress into contact with no other material than limestone, must far exceed this quantity.

Great as is the part taken by carbonic acid in the excavation of caverns, there are yet other agencies which deserve a passing notice. It has been observed in the caves of Kentucky that certain beds of an argillaceous character, impregnated with earths and alkalies, are disposed to produce salts, and that these, oozing through the pores of the stone, effloresce on the surface, and thus take their share in the disintegration of the rock, and facilitate the work of the acid-laden water. Beyond this Mr. Dale Owen has remarked upon the tendency which some calcareous rocks have to produce nitrate of lime, to which cause he attributes not a little of the disintegration which occurs in limestones.

It has often been remarked that two other phenomena almost invariably accompany the existence of caves in a limestone country—"pot-holes and ravines." When a special origin was attributed to the caves, such as the contortions of the earth's crust already alluded to, or the subterranean effects of hydrothermal springs, which was a theory suggested by an eminent French geologist to account for the existence of caves, and to which cause undoubtedly some subterranean excavations, such as those which occur in districts containing a large amount of rock salt, are due, the intimate connection between these and the caverns was not of course recognised. But when the enormous power of acid-laden water in eroding and wearing away limestone was once admitted, it was easy to see that many of the surface peculiarities must be attributed to the same agency. The pot-holes which occur in all cave districts are funnel-

shaped cavities, to which the varied names of "cirques," "betoires," "chaldrons du diable," "marmites de géants," "sinks," and "swallow-holes," have been applied.

Streams, and even rivers, may often be observed to flow for many miles on the surface, and then suddenly to plunge down into the depths of the earth, the swallow-holes, or as they are sometimes termed, "swallet-holes," being the point of disappearance. But at other times the pot-holes seem to have been the original "reservoirs" in which the rainfall was collected prior to its disappearance between the underground cracks and joints in the rocks. Originally merely shallow basins or hollows upon the surface, they have been gradually enlarged by the combined chemical and mechanical action of the water, until they reach the vast proportions of the vertical shaft, about a hundred feet in length, known as the Helln Pot, near Selside, in Ribblesdale. It is to such beginnings as this that the limestone caves immediately owe their origin. The water which thus finds its way into the interior must gain an exit somewhere, though a geologist in former times hazarded the opinion that the stream of water thus penetrating into the interior of the earth served to extinguish the fires which were supposed to exist at its centre. Often, as we know, these underground streams travel several hundred feet vertically, and sometimes many miles in a more or less horizontal direction; but though occasionally they enter the sea direct, they generally seem to find their way again to the surface, having gradually eaten and worn their way through the solid rock.

Year after year and century after century the uninter-

mittent action of the stream goes on, until at length vast excavations are made in the depths of the earth, and the floors of the subterranean caverns form the beds of flowing rivers, which presently emerging to the light of day wind their course through the open country. Here, then, we obtain evidence of the intimate connection which exists between caves, ravines, and valleys. The stream emerging from the more or less perpendicular face of the rock not only increases the passage through which it flows by its own power of erosion, but it also forms a point of weakness, and affords an additional place of vantage to the various climatic influences which play their part in the process of subaërial denudation. Thus there is ever a tendency on the part of the overlying strata to break away from their attachments, so that fragments of stone, larger or smaller according to circumstances, are constantly falling from the roof of the mouth of the cavern, ultimately leading to the demolition of the face of the exposed rock. Hence, as time goes on, the entrance to the subterranean chasm gradually recedes from its original position, until eventually it may even reach the initial pot-hole, when nothing will remain to indicate the former existence of a cavern but a deep ravine, which will often be seen opening out into a less rugged valley. So impressed with this view was an eminent French geologist, M. Desnoyers, that he has termed ravines "*cavernes à ciel ouvert,*" and Mr. Boyd Dawkins has suggested that the celebrated gorge of the Avon near Bristol owes its origin to the gradual breaking away of the roof of an immense cave or series of caves.

From the manner in which caves are formed, it will be

seen that a vast period of time must have elapsed since the first tiny stream commenced to eat its way into the solid rock. The period, indeed, is so vast that it is impossible to fix it by any chronological data, and we have to look to the more extended epochs of geology in order to arrive at even an approximate idea of their age. The presence of "Rhætic" fossils in one or two of the English caves has led to the belief that these existed prior to the deposition of those immense masses of secondary rocks, including the Lias, Oolite, and Chalk, as well as all the more recent Tertiary and post-Tertiary beds. Whether or not such was in fact the case, it is impossible to say; but at least we may conclude that most of the caves containing fossils must have originated at a much later date. Mr. Geikie has remarked that though very likely all caves of Miocene age may have been cleared away by denudation before the Pliocene period, yet it would be extraordinary had a similar fate befallen Pliocene caves before the immediately ensuing Pleistocene period, and he accounts for the absence of Pliocene fossils by supposing them to have been swept away by streams of running water. Attempts have been made by various observers to fix the approximate age of caves by a calculation of the rate of deposition of the carbonate of lime held in solution by the water passing through them. But before proceeding further, it may be better to glance at the manner in which this substance is deposited.

As the presence of carbonate of lime in the water is due to the excess of carbonic acid it contains, the evaporation of the acid must lead to the re-crystallisation of the

Fig. 3.—GROTTO OF ANTIPACOS.

lime, and though so long as the water continues to traverse the cavern in any considerable volume, the evaporation, and consequent crystallisation, is slight; yet any lessening of the velocity of the stream or volume of water at once leads to the deposition of large masses of pure crystalline carbonate of lime. In the still and shallow pools it shoots over the surface like "plates of ice, or is deposited in loose botryoidal masses at their sides and on their bottoms," while as water from the surface is constantly percolating through the roof, the walls of the caves become encrusted with masses of lime of the most varied and fantastic forms. Nothing can be more beautiful than the appearance of some of these stalactite caves, nor is it possible to convey any adequate idea of the multiform shapes which the pendent stalactites assume. Whatever their form, these stalactites are all due to one and the same cause—the never-ceasing drip of the lime-charged water from the roof. Grain by grain the lime is deposited, until the roof of the cave is covered with a drapery of white and glistening points, sometimes small and tapering, at others of great length or thickness. At one place may be seen a huge mass, like an inverted cone, extending from the ceiling half way to the floor, while below it is another immense cone, which has been formed by the water falling drop by drop from the stalactite above.

These stalactites sometimes attain gigantic proportions. In the Luray Cave, in Page County, Virginia, an immense mass which has fallen from the roof, and to which the inappropriate name of the fallen column has been given by the visitors, is over fifty feet in length and fourteen feet in

diameter at the thicker end. Its estimated weight is no less than 400 tons, while some of the stalactites still suspended from the roof of the same chamber are said to be upwards of 500 tons in weight, and present the appearance of a "great inverted forest of blasted trunks." The Luray Cavern presents us indeed with a great variety of the grotesque forms produced by the crystallisation of the trickling carbonate of lime. One chamber has received the name of the Fish-Market, in consequence of the strange growth of hundreds of flat sheet-like stalactites, arranged in rows like so many fish for sale, and an ingenious observer has even affirmed that there is no difficulty in identifying the species of bass, chad, perch, and mackerel, the illusion being completed by the trickling of water sufficient to give a slimy or fishy appearance to the objects. Perhaps no other cave in the world is more richly ornamented with stalactitic and stalagmitic decorations than that of Luray. The chambers are immense, measuring sometimes about 200 feet in length and 50 feet in height, and are draped or festooned with graceful folds and fringes so thin that the light of a candle reveals the entire structure within, or with the massive bosses already referred to. In the "Giant's Hall," for instance, is an apparently interminable row of prodigious glittering columns, which "rise from out the depths of shade, and are lost in the overhanging gloom," while in the so-called Cathedral is a stone organ formed of thin sheets of stalactite of various lengths, which upon being struck give out soft musical tones, so that, according to a statement in the Smithsonian Report for 1880, familiar airs can be played upon them as upon a harmonicon.

Now and again, in place of these large stalactites we find congregated together an infinite number of tiny hollow stems, about the thickness of straws, through which the water from above still continues to flow. Strange as they appear, there can be no hesitation in deciding their origin. "They were formed," says Mr. Boyd Dawkins, "by the evaporation of the carbonic acid from the surface of each drop of water as it accumulated in one spot, and the consequent deposit of carbonate of lime around its circumference." Though little can be said with certainty as to the time required for the formation of these masses, some attempts have been made to arrive at an approximate estimate by the measurement of stalagmitic bosses in the English caves.

Sometimes the formation of an inch or two of stalactite has occupied many years; while, on the other hand, a layer of stalagmite nearly half an inch in thickness was formed in the cave at Ingleborough in a single year. A very interesting instance of the rate of formation of stalagmite is afforded by an inscription left by one enterprising and ambitious visitor to Kent's Cavern nearly two centuries ago. He left his name, "Robert Hedges, of Ireland, February, 20th, 1688," engraved upon a boss of stalagmite on the floor of the cave, and the rudely-cut letters are now covered by a film of carbonate of lime about one-twentieth of an inch in thickness. At this rate it has been calculated that the upper layer of stalagmite in Kent's Cavern, measuring about five feet in thickness, must have occupied 240,000 years; and the lower layer, measuring twelve feet, 576,000 years for their deposition; while the lowest

estimates of geologists are 5,000 and 12,000 years respectively. Mr. Geikie has supposed that were the rainfall quadrupled the deposition of carbonate of lime would be largely increased; but we must not forget, in allowing for differences of this kind, that with an increase in the quantity of water passing through the cavern evaporation would probably be less, and that, therefore, there might be no very material increase in the rate of growth, except at particular points, and under peculiar conditions.

It is, then, clear that any estimate of the age of caves deduced from the rate of deposition of stalagmite cannot be regarded as satisfactory, and we are, therefore, forced to form our opinion of their age, to a great extent, from their contents, which consist partly of fossil bones and partly also of the remains of man's handiwork.

In a large number of the caves which have been examined, probably in all which have been excavated in limestone rocks, the interior presents similar characters. The lime held in solution by the water trickling through the roof of the cave not only forms stalactites, but also incrusts the walls of the cavern, and gradually finds its way to the floor. As it passes over this, a deposit of carbonate of lime is gradually formed, layer upon layer, and of great hardness. This coating of carbonate of lime, which varies much in thickness, is known as the stalagmite crust. Beneath this is generally found a yellowish or reddish fatty earth, composed, for the most part, of clay mixed with sand, in which are sometimes to be seen rounded and water-worn pebbles.

The presence of this red earth, which is equally familiar

to geologists in this country and abroad, is evidence of the fact that these caves have not for a vast period of time been submerged beneath the waters of the sea, or of an inland lake, for it is due to the slow and gradual accumulation of the insoluble material which has been left as a residue when the limestone was gradually dissolved away by the action of the rain water. How slow the accumulation of this deposit must have been will at once be recognised when it is considered how small is the quantity of foreign matter usually contained in limestone rocks, though perhaps a certain proportion may have been derived from the surface; but the difference between the silt thus carried into the caves and the true limestone refuse may frequently, if not always, be detected on careful examination. Sometimes this cave earth is loose and somewhat loamy in texture, while at others it is completely cemented together by the infiltration of carbonate of lime, when it forms a solid mass of great coherency, and can only be broken up with a pickaxe or chisel.

The extremely interesting remains of extinct and other animals which have been obtained from the limestone caves of this country and the Continent have been found almost exclusively in this red earth, or, as it is frequently termed, ossiferous clay. It must not, however, be supposed that their preservation is in any way due to the properties of the earth containing them, for in fact, where the bones remained dry, and there was no protecting covering of stalagmite, they were found to be in a completely decomposed state, and crumbled to dust the moment they were disturbed. When the stalagmitic crust is present, however,

it forms a perfect hermetical covering, and beneath it the bones have often been found not alone perfect in shape and uninjured by time, but actually retaining something of their organic substance.

The interest attaching to the cave remains is very great, as they throw an unexpected light upon the early history of man, and also reveal to us a condition of things with reference to climate and physical geography, which, until these discoveries, we could never have suspected. During what has been termed the "Pliocene" period by geologists, we find, by the organic remains contained in the various strata of this age, that the climate of England and of Europe was much higher than it is at present, and this higher temperature continued into the succeeding "Pleistocene" age, to be gradually followed by a period of arctic cold, so that the caves of Europe have witnessed strange vicissitudes of climate, and the animal remains which they contain prove how great have been the zoological changes within the era of their formation.

The existence of fossil remains of animals in the caves of Europe has long been known. In the sixteenth and seventeenth centuries they were, under the name of "*ebur fossile*," or unicorn's horn, greatly esteemed as a medicine, and were obtained in great quantity from the caves of the Hartz district, and of Hungary and Franconia. Baumann's Hole in the Hartz had already become famous at the close of the seventeenth century, and descriptions of other caves and of their contents followed at intervals, until at last a new branch of investigation sprang up, the importance of which can

hardly be exaggerated, when its bearings upon the early history of man are considered. It was long, however, before the possibility of man's existence contemporaneously with the extinct animals found in some of the oldest caves was entertained by the majority of scientific men ; but the doubt was finally set at rest in 1858 upon the discovery of undoubted human relics in the celebrated Brixham Cave in Devonshire.

As cave exploration was carried on, and evidence of one kind and another accumulated, it was found that the fossil remains contained in them indicated at least two distinct zoological eras, in the later of which the animals belonged almost exclusively to species which still inhabit Europe, while in the earlier were found the remains of a number of animals which not only are no longer to be found in this region, but many of which do not even exist in any part of the world, and of such importance has this change in the fauna been considered that the Pleistocene period has been regarded as almost equivalent in geological value to the Pliocene or the Miocene periods, or at least to be separated by as definite a line from the more recent period as are the three previous eras from one another.

One of the earliest caves examined with scientific accuracy was that of Gailenreuth in Franconia, which was described by Dr. Buckland in his celebrated "Reliquiæ Diluvianæ" in 1824. Beneath the stalagmite floor were found immense quantities of animal remains, including the bones and teeth of the lion, hyena, cave bear, grizzly bear, mammoth, Irish elk, and reindeer, all of which have long ceased to exist in that region, and some, such as the

mammoth and the cave bear, are quite extinct. Having learnt in the caves of Germany what was to be learnt of cave exploration, Dr. Buckland returned to England, and undertook the investigation of the caves of this country. As from them is to be gathered as much concerning the past history of the animal life of Europe as is to be obtained by a more extended search, we may confine ourselves to a brief examination of the contents of some of the English caves.

From the nature of the remains contained in the caves of earliest geological date, we are justified in believing that a high temperature must at one time have prevailed over the whole of Europe. Yet the evidence upon this point is somewhat contradictory, for in some of the earliest caves have been found the bones of the musk-sheep and of the mammoth, both of which doubtless flourished best in a cold climate; while, on the other hand, the presence in the caves of Kirkdale, Wookey, Uphill, and Cheddar, of such animals as the hyena, the panther, lion, hippopotamus, rhinoceros, and elephant, all of which are at the present time creatures of essentially tropical habits, leave little room for doubt that the climate was considerably higher in former times than now. The presence of animals of more temperate climes associated with these tropical forms has, therefore, been accounted for—by no means satisfactorily, however—by supposing that temporary changes of climate enabled first one and then another group of animals to frequent the same haunts and pastures.

It has often been matter of speculation and wonder how the numerous remains which are met with in caves

came to occupy their present position. Sometimes undoubtedly they have been washed in by the agency of running water; but in many cases there is no doubt whatever that the caves were the lairs or dens of beasts of prey which lived upon the wild animals roaming the primeval forests of Britain, and that the bones which we now find are the records of unnumbered feasts. The proof of this fact is to be found in the condition of many of the bones, which have obviously been gnawed and eaten by wild beasts, and while all the softer parts have disappeared, only the hardest and most solid now remain. Doubtless the animals by which these remains were left were the spotted hyenas, which appear to have existed in considerable numbers in the Pleistocene age. No other creature perhaps possesses jaws so powerful, or teeth so capable of consuming solid bone. A comparison has been instituted between the bones left by hyenas kept in confinement and those which are found in the "hyena caves," and the similarity between them leaves no room for doubt that the fragmentary character of many of the cave remains is due to this cause. The soft portions of the extremities of the leg bones of oxen or bisons are found completely demolished, while the shaft is generally broken in such a manner as to admit of the extraction of the marrow. The head of the rhinoceros has sometimes been found in caves, but generally all that remains is the small solid nasal bone upon which the front horn was supported. Other carnivorous animals, however, doubtless played their part in bequeathing to us these fragmentary remains of extinct creatures. Amongst them were the lion, the

panther, and another feline to which the name of *Felis Caffer* has been given. There also existed a large bear, known as the cave bear (*Ursus spelæus*), which seems to have closely resembled the grizzly bear of North America; while in early Pleistocene times, at least, existed a huge animal, known as the *Machairodus*, or sabre-toothed tiger, which possessed a masticating apparatus more formidable than that of any existing beast of prey, and which is known chiefly by the immense sabre-shaped canine teeth, with serrated edges, which are occasionally met with in the cave-earth.

Vast as is the lapse of time since the hippopotamus, rhinoceros, and lion roamed the country in a wild state, and since the spotted hyena preyed upon such creatures as he was able to kill or to find dead, there is not wanting evidence to prove that man, even at that early period, had found a place upon the earth. In the celebrated cave at Wookey Hole in the Mendip Hills, which, from the quantity of half-consumed bones it contained, must for ages have been a favourite resort of hyenas, indications of the presence of man were found which admitted of no doubt. These consisted of an oval implement of flint, very roughly fashioned, a short arrow-head, and some fragments of chipped flint, together with two bone arrow-heads of very primitive workmanship, yet obviously the result of man's handiwork.

In caves containing remains of a later date, we find that all traces of the formidable Carnivora, and of the huge Pachyderms have disappeared, while the influences of man's presence greatly increase in importance. It is clear that

the early inhabitants of Europe and of Britain must have dwelt commonly in caves when they were no longer infested with hyenas, and the relics of Neolithic man are numerous and interesting. We see amongst the animal remains the bones of the dog, pig, horse, ox, and goat, all of which were doubtless domesticated; while the wolf, the fox, the bear, the stag, and the wild boar, have taken the place of the more formidable *feræ* of earlier days. Everything indeed indicates an amelioration in the condition of primeval man. No longer contented with rude chipped flints, we find him possessed of stone implements carefully ground and polished. His ornaments too, of bone and horn, attest an advance upon the rude ideas of his Palæolithic predecessors, while fragments of pottery prove how great was his advance in social culture. We find, too, that some respect was paid to the dead, and caves were given up to purposes of sepulture, the bodies being generally placed in a contracted position within a rock cavity, and preserved from the attacks of wild animals by the placing of large slabs of stone at the entrance.

As time proceeded we find indications of the gradual advance of mankind in arts and perhaps intelligence. Fragments of kitchen utensils and grinding stones prove him to have been no longer dependent upon the chase for his sole or chief means of support, while the pottery and implements indicate marked progress, until at last we arrive at a period when the caves were no longer used habitually as places of abode, but were made into temporary shelters probably from the attacks of enemies. Thus we find implements and ornaments of bronze and other metals, the

workmanship of which indicates a high condition of culture, and finally we reach a time when the presence of Roman and other coins fixes the historic date of the cave occupation, when we may be sure it was not of a permanent kind.

Though we have confined ourselves for the most part to notices of the English caves, it must not be supposed that these alone furnish objects of interest to the inquirer. We have already briefly referred to the quaint paintings discovered by Sir T. Mitchell in the sandstone caves of Australia, and somewhat similar productions of rude uncultured art have been observed in South Africa, but the date of these is doubtless recent, though the present inhabitants appear to have no knowledge of their origin. But in eastern Australia have further been observed caves in the limestone rocks of the Blue Mountains, which contained fossil bones of great interest from the similarity which they bore to those of the animals still inhabiting that region. Amongst these were two gigantic species of kangaroo, stated by Professor Owen to have been at least one third larger than the largest kangaroo now known, while smaller species, differing to a greater or less extent from any now existing, as well as a burrowing wombat, a climbing phalanger, a dasyure, and other creatures resembling, yet not identical with the animals now inhabiting the continent of Australia, prove how vast must have been the changes which have occurred since these creatures occupied the region in which their remains are still preserved.

Though hitherto we have said but little of the caves of America, yet it is in that country that the most stupendous examples are to be found. In Kentucky,

for instance, the sub-carboniferous limestone presents us with a most extraordinary series of caves, which extend through the counties of Christian, Edmonson, Grayson, Hart, Butler, Logan, Todd, and Trigg, in the second of which is the celebrated Mammoth Cave. This gigantic excavation extends, in its various explored ramifications, no less than 223 miles beneath the surface of the earth, the actual length of the cave being estimated at 150 miles, and Mr. Dale Owen has calculated that the average height and width of the passages being reckoned as seven feet, no less than 12,000,000 cubic yards of material have been gradually excavated by the slow passage of carbonic-acid laden water through the rock.

In these vast caverns are found strange creatures which are apparently specially adapted for their underground dwelling-place, and it is that these might be briefly described that the Mammoth Caves have been specially referred to. First amongst these is to be observed the curious fish to which the name of *Amblyopsis spelæus* has been given. These fish are of small size, the largest yet observed being five inches in length. They are white in colour, and when swimming about at the surface in search of food have been compared to small aquatic ghosts. Their most striking peculiarity is, however, their complete blindness, which is accounted for by their having been for unnumbered generations cut off from the light of day. Nevertheless, the optic nerves seem to be as well developed as in other fishes, but the eyes are represented only by tiny black spots beneath the skin. Deprived of sight, the little *Amblyopsis* is compensated by its marvellous powers of hearing and feeling.

Though swimming at the surface of the water, and easily seen, it is very difficult to catch, as the slightest noise causes it to turn suddenly down and hide itself beneath stones at the bottom. Its movements are very rapid, and it seems to be guided to its prey by tactile organs, apparently connected with folds of skin covering the head, which apprise it of the smallest motions in the water in its vicinity. This little fish is nearly related to the shore minnows and pickerels, and not, as might have been supposed, to fishes inhabiting rivers or fresh-water lakes. Though blind itself, another fish has sometimes been found in the stomach of the *Amblyopsis,* possessed of well-developed eyes, and of a dark blackish colour, but whether this is confined exclusively to caves seems yet uncertain. Other blind fish have, however, been met with in caves. In the caves of Cuba have been found two species of *Lucifuga,* which possess no external eyes, but are furnished with minute hair-like organs of touch which doubtless amply supply their place. These, like the *Amblyopsis,* find their nearest allies in marine forms of fishes, though they bear some relation to the fresh-water ling of America. And again, in the Wyandotte Cave have been found two fishes belonging to the same family, one totally blind, the other with well-developed eyes, both of which find their nearest relatives in the waters of the sea. It has, therefore, been conjectured that the caves were originally occupied by salt water, and that their present inhabitants are survivors from an early period—perhaps the close of the Pliocene era.

In the American caves we have no notice of the existence of reptiles specially adapted for an underground life, but

from a cave in the vicinity of Adelsburg has been obtained a species of salamander which appears to be entirely confined to the cave, and which is the solitary representative of the vertebrata in the cave-fauna of Europe. But of the lower animals there are many examples. In the Mammoth Cave is found a small blind crayfish, in which the eyes of the adult are quite rudimentary, while in the young they are fairly developed, though useless, thus leading to the conclusion that blindness was first "acquired" by old individuals, and by them transmitted to their offspring. In the caves both of America and of Europe have been found specimens of Isopod crustaceans, which seem to be almost if not quite identical. These creatures belong to the same group of animals as the familiar wood-lice of our gardens, but the nearest allies of the cave species are to be found in the genus Idotea, which is confined with one or two peculiar exceptions to salt water, so that here again we find reason to believe that the caves have at one time been submerged beneath the sea, as we do to some extent in the caves both of Europe and America in the presence of a little creature resembling the common Sand-hopper (*Gammarus*) of our coasts, though some species are also to be met with in fresh water. Though several insects have been found in the American caves, it is hard to say whether they are all confined to such habitations. Two species of flies were found in the Mammoth Cave, at a distance of three or four miles from the entrance, but as these were brightly-coloured and possessed well-developed eyes they may have been accidental visitants. Two wingless grasshoppers from the same cave also possessed eyes, but two beetles were totally blind. One,

Fig. 4.—MAMMOTH CAVE, KENTUCKY.

a *Carabus*, was of a pale reddish horn-colour, and apparently had no trace of eyes, while the other, a Silphid or burying beetle, was of a greyish-brown colour, and showed two small whitish spots, which have been very doubtfully regarded as rudimentary eyes.

Both in the Mammoth and Adelsburg caves small eyeless spiders have been found, and in the former a single species of Myriapod was discovered, the body of which was clothed with fine hairs which have been supposed to be organs of touch, though perhaps on insufficient grounds.

These blind inhabitants of caves from which daylight is for ever banished are peculiarly interesting as showing how greatly living creatures are influenced by the nature of their surroundings, for we cannot suppose that these animals have always been blind, and we can account for the presence of rudimentary eyes in so many of them only by supposing that their remote ancestors possessed these organs in their full development, and gradually lost them through disuse. Thus from whatever aspect we regard these interesting natural excavations they are fraught with intense interest. The history of their formation alone would occupy a volume, while their contents, both animate and inanimate, open out to us a new page in the story of the earth's long history, much of which yet remains to be deciphered.

THE GLOW-WORM AND OTHER PHOSPHORESCENT ANIMALS.

By G. G. Chisholm, M.A., B.Sc.

In certain parts of England, those who take an evening stroll, especially by damp and sheltered spots, in the late summer or autumn months, may chance to find their walk enlivened by the spectacle of, perhaps, hundreds of luminous spots scattered over the grass and moss. If the stroller walks up to one of these spots and examines it, he will find that the mild greenish light that has attracted his attention proceeds from a living creature about half an inch in length, of such a form as to lead to its being called in popular speech a "worm."

A worm, however, it is not. If the observer is even slightly acquainted with natural history, he will be able to see, on examining it, that it has all the essential characters of an insect, in the strict sense of that term. It has a body divided into three main segments, the *head* forming one, while the second, called the *thorax*, is furnished with six legs; and the remainder, the *abdomen* (itself in this case subdivided into a number of segments), is without legs. Seen from the back, it is true, all this is not very apparent. The shield covering the thorax projects on the back so far over the head that this cannot be recognised as a distinct segment, and it is not easy to see from above where the legs are attached; but on turning the creature

over, and examining it from the under side, all the essential characters above mentioned are at once plainly visible.

But where are the wings? Wings, to be sure, are present in most insects, and in fact, as a rule, two pairs of wings. These appendages are, however, not essential. They may be reduced to a single pair, and they may be absent altogether. The latter seems to be the case in the insect now under examination. And so it would prove if all the shining "worms" adorning the grass were examined one after the other.

Yet it would be a mistake, or at least misleading, to say that this insect is without wings. The "glow-worm" is, in fact, the female of a species of insect, of which the male has the normal two pairs of wings, but has very little of the power of emitting light possessed by the female. The nature of these wings, together with other characters, shows that the insect belongs to the great order of the Coleoptera (the beetle order), in which the outer pair of wings are hardened, and are more properly wing-covers, or *elytra*, as they are called, than true wings.

It is chiefly in the southern counties of England that this insect is to be seen; but it is not confined to these. Even in the south of Scotland it may be met with occasionally; but there it is rare. As already indicated, late summer and autumn are the times when its light is most frequently observed, but on a few occasions it has been seen to shine as late as the middle of November.

The scientific name of the glow-worm is *Lampyris noctiluca*, and the name of *Lampyridæ*, derived from a Greek

word signifying "to shine," is applied to a whole family of insects, numbering upwards of five hundred species, in which the power of emitting light is very general. They

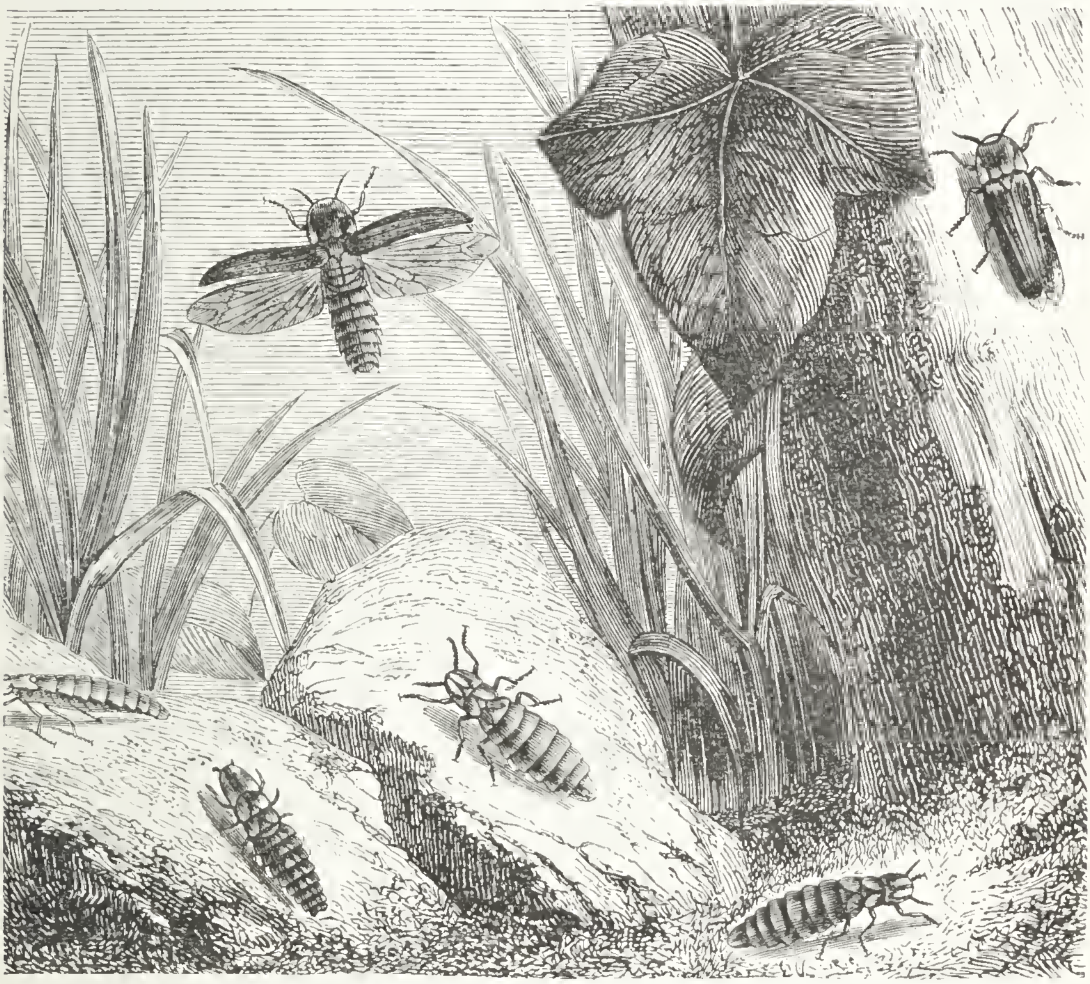

FIG. 1.—THE GLOW-WORM, SHOWING THE MALE (WINGED), THE FEMALE (UNWINGED), AND THE LARVA (WITH SHORT ANTENNÆ, AND WITHOUT CLAWS AT THE END OF THE LEGS).

are natives chiefly of North and South America, and it is in the tropical parts of that continent that the most brilliant specimens are to be found. *Lampyris noctiluca* is the only British species of the whole family. It is not, however, confined to Britain, being abundant over all the

warmer parts of Europe, and in these parts there are found other members of the genus in which the light is conspicuous only in creeping forms. In some cases, as in the *Lampyris splendidula*, the light in the male is very distinct, and can be seen when the insect is flying; and in other cases, as in the *Lampyris Italica*, a native (as the name indicates) of Italy, the female herself has wings, and may be seen darting about as a luminous speck in the air. This latter is the smallest of all phosphorescent insects, being scarcely a third of an inch in length. In Italy these fire-flies are regarded with a peculiar dread by the common people, who entertain the curious superstition that they are spirits, and come out of the graves.

The precise seat of the light in the common glow-worm is in the tail. In the female there are three pairs of thin white sacs in three of the last segments of the abdomen, immediately beneath the skin on the under side; and it is from these sacs that the light proceeds. In the male there are only two pairs of luminous sacs, and the light emitted by them is much feebler. In both cases the sacs are in contact with nerve-ganglia and large air-tubes, or *tracheæ*, tubes which ramify through the body of an insect, and by means of which it breathes. The light is a steady one as long as it shines; but it is not constant, and appears to be undoubtedly under the control of the insect. Very frequently it is withdrawn when the insect is handled, but this is not always the case; and in Kirby and Spence's "Introduction to Entomology" an instance is mentioned in which the writer captured two glow-worms while

brilliantly shining, in order to examine them, and found that while one of the two soon after extinguished its light, the other continued to shine, and "while it did this it was laid upon its back, the abdomen forming an angle with the rest of the body, and the last or anal segment being kept in constant motion."

The light of the glow-worm is said to begin to grow faint soon after midnight, but if we may trust one close observer of nature, it sometimes shines much longer, and its diminution is to be taken as a sign of the approach of morning.

> "The glow-worm shows the matin to be near,
> And 'gins to pale his ineffectual fire."

By day its light is not to be seen at all, even in shady places, which it most frequents.

Even the larva, or caterpillar form of the glow-worm, is not without its light, though this is very inconspicuous. In appearance this larva is very like the fully-developed female, from which, however, it can always be distinguished by the want of claws at the end of its legs. To the farmer this larva, and hence the glow-worm itself, is a valuable friend, for it feeds wholly on snails, and in that way detroys large numbers of these depredators. It appears early in the year, and is thus ready to attack the snails as soon as they come out of their hiding-places.

Though the glow-worm is, as we have said, the only member of the Lampyridæ belonging to Britain, it is not the only inhabitant of the land which in this country may be seen to give out what is called a phosphorescent light. There is a genus of centipedes called *Geophilus*,

which contains at least two species possessed of this power, and one of these, *Geophilus electricus,* is not uncommon in this country. It is generally to be seen crawling along paths, and when phosphorescent not only exhibits rows of luminous points on both sides of its body, but leaves a glowing trail behind it, sometimes a foot and a half long. The cases in which one or two British insects not belonging to the Lampyridæ, such as the mole-cricket (*Gryllotalpa vulgaris*) and the daddy-longlegs (*Tipula oleracea*), are reported to have been seen in a phosphorescent condition, are at least very exceptional, if they can be regarded at all as sufficiently authenticated.

But it is in warmer countries that this phenomenon of phosphorescence in insects and allied creatures is to be seen in its greatest brilliance. Besides the numerous *Lampyridæ,* there is in America and the West Indies another phosphorescent insect, far more brilliant than all the others. The insect referred to is a member of the Elateridæ, another family of Coleoptera, the family which includes the common skip-jack, the larva of which, well known to farmers as the wire-worm, is remarkable for the devastation it sometimes works in fields of corn. The brightest of the phosphorescent allies of this English skip-jack was formerly called by entomologists *Elater noctilucus,* but is now referred, with all its luminous kindred, to the genus *Pyrophorus.* Its larva, it may be mentioned, is sometimes just as destructive among the sugar-canes of the West Indies as that of the skip-jack is among the corn-fields at home.

It is, however, the full-grown insect, and not the larva, which must now engage the attention, on account of the

property which it possesses in common with the English glow-worm, but in a much higher degree. The striking nature of the spectacle which it presents has often been described by travellers.

"No sooner," says one writer, "do the lofty and umbrageous trees begin to throw their shadows across the landscape than occasional specks of light are seen to flit amidst the growing obscurity. As the darkness increases these become more numerous; they mount into the air, and shoot athwart the gloom like igneous meteors, and when the underwood is disturbed they rise in such numbers that they spangle the air as with a thousand stars."

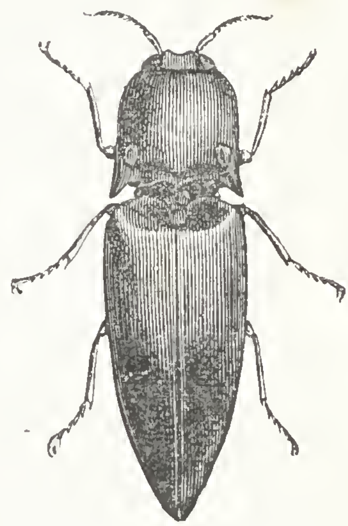

FIG. 2.—THE CUCUYO, OR WEST INDIAN FIRE-FLY (*Pyrophorus noctilucus*).

The insect emitting the light in this case is nearly, if not quite, an inch in length, and the light is common to both sexes. When examined resting, the only luminous parts visible are two elevated spots in the back of the thorax, and the light proceeding from these does not account for the degree of luminosity exhibited by the insect when flying. The reason of this is that when the wings are closed another and more intense light is hidden on the under surface—a light that can be seen only when the abdomen is fully extended. This light is in the form of a transverse band just behind the thorax, and when the wings are closed the abdomen is bent slightly downwards, and this has the effect of pushing the light under the

opaque thoracic covering on the under side. To examine this light, it is necessary first to thrust aside the strong wing-covers which keep the abdomen in a slightly bent position, and then to extend the latter to its full length. But in flying the insect always has the abdomen stretched out, so that the light underneath is exposed.

The luminosity in the thoracic spots of *Pyrophorus noctilucus* is said to be directly under the control of the insect, so that these spots can be lit up or extinguished at will. When the light appears, it is first seen in the middle point of each spot, and it gradually extends towards the circumference, and when it is withdrawn it disappears in the reverse order. The light underneath, on the other hand, would seem not to be under the control of the insect at all, except in so far as it can be exposed or hidden in the manner just indicated.

The colour of the light is greenish, like that of the English glow-worm, and, indeed, of most phosphorescent insects. The general colour of the insect itself is a dull green, and the wing-covers are marked with delicate rows of minute punctures extending from the base to the apex, but most obvious at the base.

The brilliancy of the light is such that the smallest print can be read by means of that proceeding from the thoracic spots alone when a single insect is moved along the lines; and Peter Martyr, a Spaniard, who visited and described the Spanish settlements in the West Indies in the early part of the sixteenth century, records that at that time the natives were in the habit of using them in various ways for illumination. In travelling at night, he informs

us, they used to tie one to each great toe, and on fishing and hunting expeditions they would make torches of them by fastening several together. If these accounts are trustworthy, we may assume that when the insects were so employed they were tied in such a manner that the light underneath the body remained always exposed.

If we may believe the same historian, this "fire-fly" was also useful in another way to the inhabitants of the West Indies in his day, namely, in extirpating mosquitoes, which, he says, they devoured very greedily. He describes how the people used to go out at night to catch them for this purpose, waving fire-brands in the air, and calling out *cucuie, cucuie.* Attracted by the light of the fire-brands, and, as the people themselves imagined, by the invocation *cucuie,* the fire-flies would gather round, and a number of them being captured, they were let loose in the houses, where they at once made themselves useful by pursuing the minute, but pestilent, insects with which the rooms were infested. Mr. Gosse, however, who had ample opportunities of studying the habits of the fire-flies in the West Indies, throws ridicule on this account, and for his own part refuses to believe that they could ever have been employed in this way. Circumstantial as Peter's narrative is, it does not seem very likely that if the fire-flies really could be used to render such an important service in countries infested by the mosquito, the practice of employing them for that purpose would ever have died out.

As to another practice followed by the inhabitants of the West Indies, that of using this fire-fly for ornament, there is no doubt whatever. Spanish ladies are in the habit

of enclosing them in little bags of lace or gauze, and wearing them amidst their hair or disposed about various parts of their dress; and at one time it was the practice on certain festival days in June to collect them in great numbers, and tie them "all over the garments of the young people, who galloped through the streets on horses similarly ornamented, producing on a dark evening the effect of a large moving body of light."

It has been already indicated that the genus Pyrophorus includes other species of luminous insects besides *Pyrophorus noctilucus,* but this species appears to be the commonest and most widely distributed, as well as the most brilliant. It is abundant in the West Indies, twenty degrees north of the equator; and Darwin mentions that it was the commonest fire-fly at Bahia, in Brazil, about thirteen degrees to the south of that line.

Various other foreign insects are stated to have been seen in a luminous condition on certain occasions, but we will mention only two others whose phosphorescent property, whether real or supposed, is expressed both in their popular and their scientific names. These are the lantern-fly (*Fulgora laternaria,* Fig 3.) and the candle-fly (*Fulgora candelaria*), the former a native of Guiana and the latter of China. In these, as in all other members of the same genus, the forehead is produced in the form of a curiously-shaped snout, the exact figure of which differs in different species; and it is in that snout that the luminosity is said to be seated. But in spite of the fact that this property is so expressly ascribed to these insects by their very names, it is still an unsettled point whether they really are

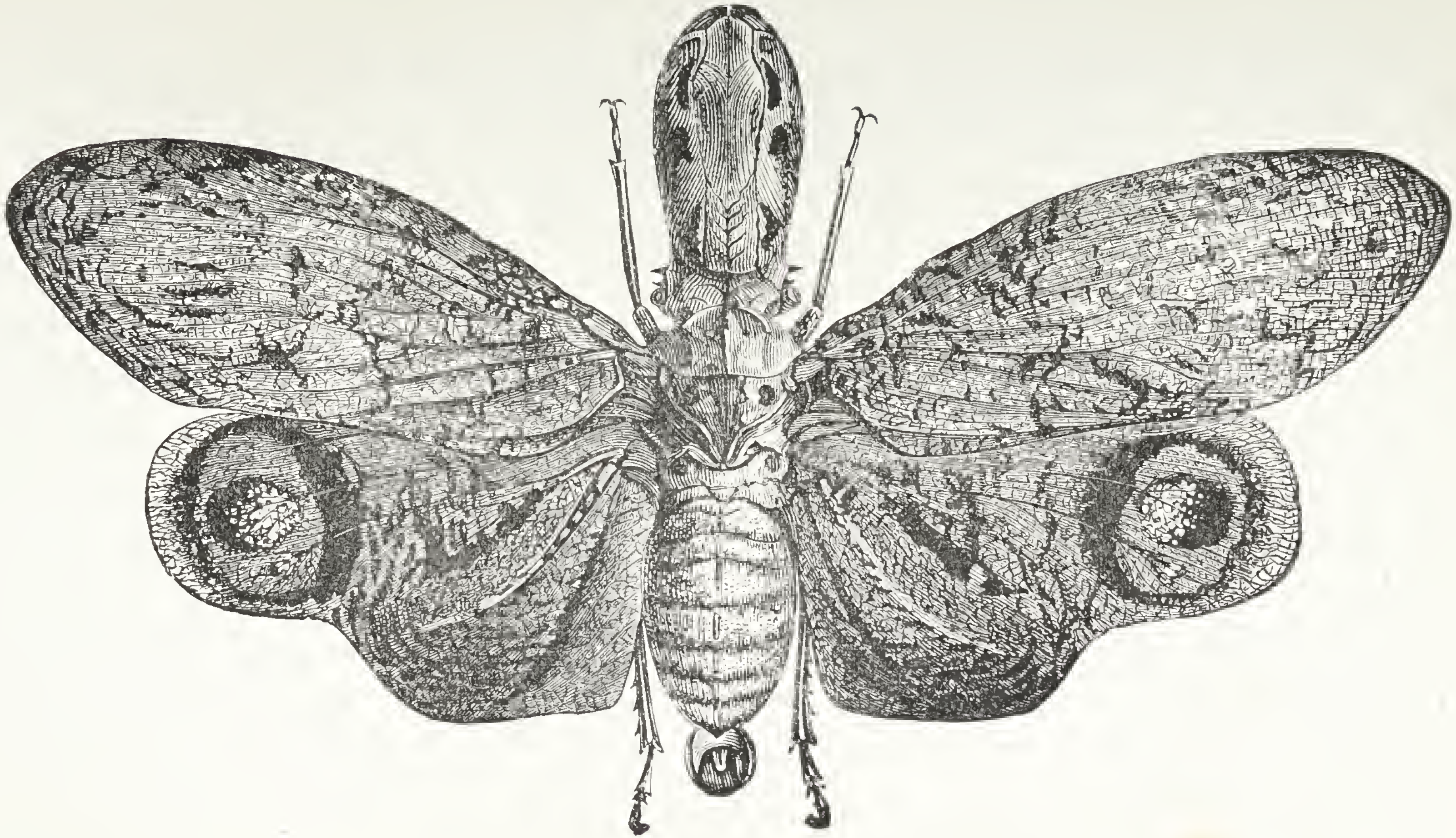

Fig. 3.—THE LANTERN-FLY (*Fulgora laternaria*).

ever luminous at all. If they are so, there can be no doubt that this luminosity is not a normal condition, seeing that several naturalists who have had abundant opportunity of observing them deny that they ever saw them giving out light; but, on the other hand, there seems to be pretty good evidence in regard to both insects that in certain cases the phenomenon has actually been witnessed.

It is not merely on land that this phenomenon of phosphorescence is to be seen in living forms. Among marine animals, indeed, it is a phenomenon much more general, much more splendid, and, we may add, much more familiar to those who live on our coasts. There must be many in the British Isles who have never had the opportunity of seeing the light of the glow-worm, but there can be few of those who have frequented in summer any part of our coasts, who have never seen that beautiful greenish light which is then so often visible, especially on our southern shores, when the water is disturbed by the blade of an oar or the prow of a boat or ship. In some cases, even on our own shores, the phenomenon is much more brilliant, every rippling wave being crested with a line of the same peculiar light, and in warmer seas exhibitions of this kind are much more common. It is now known that this light is due to a minute living form, to which we will afterwards return.

But before going on to speak in some detail of the organisms to which the phosphorescence of the sea is due, it will be as well to mention that the kind of phosphorescence just spoken of is only one mode in which the phenomenon is exhibited on the ocean. Though sometimes the light is shown in continuous lines whenever the surface

is disturbed, at other times, and, according to M. de Quatrefages, more commonly, the light appears only in minute sparks, which, however numerous, never coalesce. "In the little channel known as the Sund de Chausez," he writes, "I have seen on a dark night each stroke of the oar kindle, as it were, myriads of stars, and the wake of the craft appeared in a manner besprinkled with diamonds." When such is the case the phosphorescence is due to various minute animals, especially crustaceans: that is, creatures which, microscopically small as they are, are yet constructed more or less on the type of the lobster or cray-fish.

At other times, again, the phosphorescence is still more partial. "Great domes of pale gold with long streamers," to use the eloquent words of Professor Martin Duncan, "move slowly along in endless succession; small silvery discs swim, now enlarging and now contracting, and here and there a green or bluish gleam marks the course of a tiny, but rapidly rising and sinking globe. Hour after hour the procession passes by, and the fishermen hauling in their nets from the midst drag out liquid light, and the soft sea jellies, crushed and torn piecemeal, shine in every clinging particle. The night grows dark, the wind rises and is cold, and the tide changes; so does the luminosity of the sea. The pale spectres below the surface sink deeper, and are lost to sight, but the increasing waves are tinged here and there with green and white, and often along a line, where the fresh water is mixing with the salt in an estuary, there is a brightness so intense that boats and shores are visible. . . . But if such sights are to be seen on the surface, what must not be the phosphorescence

of the depths! Every sea-pen is glorious in its light, in fact, nearly every eight-armed Alcyonarian is thus resplendent, and the social *Pyrosoma*, bulky and a free swimmer, glows like a bar of hot metal with a white and green radiance."

Such accounts are enough to indicate how varied and how general a phenomenon is the phosphorescence of the sea. To take notice of one tithe of the points of interest summed up in the paragraph just quoted would occupy many pages, and we must therefore confine the attention to a few of the most interesting facts relating to marine phosphorescence.

And first, we will return to that form of marine luminosity to which we first referred: what is known as the general or diffused phosphorescence of the sea. From this mode of describing it the reader must not infer that the surface of the ocean is ever to be seen all aglow in one sheet of continuous light. So far, at least, as was ever observed by M. de Quatrefages, who studied this phenomenon carefully and during long periods on the coasts of Brittany and elsewhere, no light was visible when the surface of the sea was perfectly still. On the other hand, when the sea exhibits in a high degree the phenomenon of diffused phosphorescence, no disturbance can be too slight to cause the water to shine with that peculiar characteristic gleam. Drop but a grain of sand upon its surface, and you will see a point of light marking the spot where it falls, and from that point as a centre a number of increasing wavelets, each clearly defined by a line of light, will spread out in circles all round.

The cause of this diffused phosphorescence was long the

subject of curiosity, and was long unknown, but more than a hundred years ago (in 1764) the light was stated by M. Rigaut to proceed from a minute and very lowly organism, now known as *Noctiluca miliaris* (Fig. 4); and subsequent researches have confirmed this opinion. This Noctiluca is a spherical form of not more than one-fiftieth of an inch in size, with a slight depression or indentation at one point, marking the position of a mouth leading to a short digestive cavity, and having close beside it a filament, by means of which it probably moves about. The sphere is filled with protoplasm, in which there is a nucleus and one or more gaps, or "vacuoles." Such is nearly all the structure that can be discerned with the aid of the microscope in this simple organism.

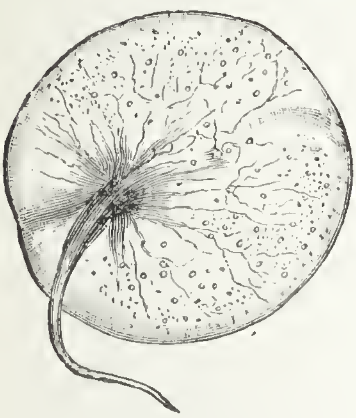

FIG. 4.—*Noctiluca miliaris.*

Nevertheless, this lowly form is the chief cause of that diffused phosphorescence which is sometimes seen over a wide extent of the ocean. How innumerable the individuals belonging to this species must therefore be may be left to the imagination. Probably the Noctiluca is not rivalled in this respect even by microscopic unicellular algæ which compose the "red snow."

By filtering sea-water containing Noctilucæ its light can be concentrated, and it has been found that a few teaspoonfuls will then yield light enough to enable one to read holding a book at the ordinary distance from the eyes —about ten inches.

A singular and highly remarkable case of diffused marine phosphorence was observed by Nordenskiöld during his voyage to Greenland in 1883. One dark night, when the weather was calm and the sea smooth, his vessel was steaming across a narrow inlet called the Igaliko Fjord, when the sea was suddenly observed to be illumined in the rear of the vessel by a broad but sharply-defined band of light, which had a uniform somewhat golden sheen, quite unlike the ordinary bluish-green phosphorescence of the sea. The latter kind of light was distinctly visible at the same time in the wake of the vessel. Though the steamer was going at the rate of from five to six miles an hour, the remarkable sheet of light got nearer and nearer. When quite close, it appeared as if the vessel were sailing in a sea of fire or molten metal. In the course of an hour the light passed on ahead, and ultimately it disappeared in the remote horizon. The nature of this phenomenon Nordenskiöld is unable to explain; and unfortunately he had not the opportunity of examining it with the spectroscope.

If we come now to consider the more partial phosphorescence of the sea, we find that it is due to animals belonging to almost every group of marine forms—to Echinoderms, or creatures of the sea-urchin and star-fish type, to Annelid worms, to Medusidæ, or jelly-fish, as they are popularly called, including the "great domes" and the "silvery discs" of the passage above quoted from Professor Martin Duncan, to Tunicates, among which is the Pyrosoma, to Molluscs, Crustaceans, and in very many cases to Actinozoa, or forms belonging to the type of the sea anemone and the coral polyp.

Of these we will single out only a few for more special notice.

Many of the Medusidæ, or jelly-fish, possess the character of which we are speaking. In some cases the phosphorescence is spontaneous among them, but in others it is not so; the creature requires to be irritated or stimulated in some way before it will emit the light. It is spontaneous, for example, in the *Pelagia phosphorea*, but not in the allied *Pelagia noctiluca*, a very common form in the Mediterranean.

In both of the jelly-fish just mentioned the phosphorescence, when displayed at all, is on the surface of the swimming disc, and this is most commonly the case with the whole group. Sometimes, however, the phosphorescence is specially localised. In some forms, as in *Thaumantias pilosella* and other members of the same genus, it is seen in buds at the base of tentacles given off from the margin of the swimming-bell. In other cases it is situated in certain internal organs, as in the canals which radiate from the centre to the margin of the bell, or in the ovaries. It is from this latter seat that the phosphorescence proceeds in *Oceania pileata*, the form which gives out such a light that Ehrenberg compared it to a lamp-globe lighted by a flame.

The property of emitting a phosphorescent light, sometimes spontaneously and sometimes on being stimulated, is likewise exemplified in the Ctenophora, a group resembing the Medusidæ in the jelly-like character of their bodies, but more closely allied in structure to the Actinozoa. But we will pass over these cases in order to dwell

more particularly on the remarkable tunicate known as Pyrosoma, a name indicative of its phosphorescent property, being derived from two Greek words signifying fire-body. As shown in the illustration (Fig. 5), Pyrosoma is not a single creature, but is composed of a whole colony of individuals, each of which is represented by one of the projections on the surface of the tube, closed at one end, which they all combine to form. The free end on the exterior contains the mouth, while there is another opening in each individual towards the interior of the tube. Such colonies, which swim about by the alternate contraction and dilatation of the individuals composing them, are pretty common in the Mediterranean, where they may attain the length of perhaps fourteen inches, with a breadth of about three inches. In the ocean they may reach a much greater size. Mr. Moseley, in his "Notes of a Naturalist on the *Challenger*," mentions a giant specimen which he once caught in the deep-sea trawl, a specimen four feet in length and ten inches in diameter, with "walls of jelly about an inch in thickness."

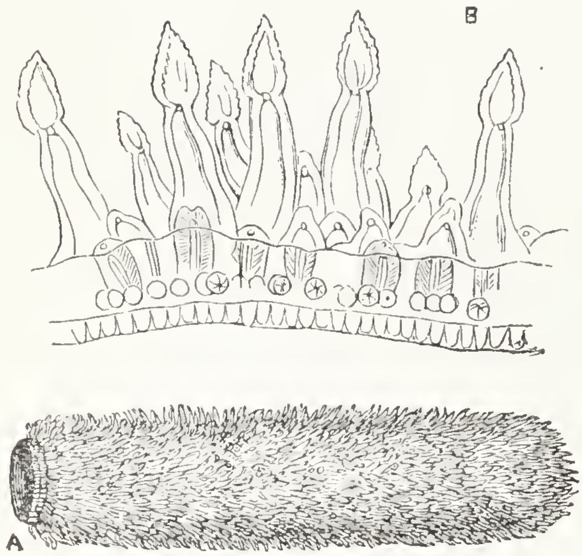

FIG. 5.—A, PYROSOMA. B, PORITON, MAGNIFIED.

The same naturalist states that the light emitted by this compound form is the most beautiful of all kinds of

phosphorescence. When stimulated by a touch, or shake, or swirl of the water, it "gives out a globe of bluish light, which lasts for several seconds, as the animal drifts past several feet beneath the surface, and then suddenly goes out." He adds that on the giant specimen just referred to be wrote his name with his finger as it lay on the deck in a tub at night, and in a few seconds he had the gratification of seeing his name come out in "letters of fire."

Among Molluscs, the best known instance of phosphorescence is in the rock-boring *Pholas*, the luminosity of which after death is mentioned by Pliny. But it is not merely after death that *Pholas* becomes luminous—a phenomenon perfectly familiar even in the case of many fish, especially the herring and mackerel. It was long before the luminosity of the living animal was known, but this is now a well-ascertained fact; and Panceri, an Italian naturalist, recently dead, has been able to discover in this, as in several other marine phosphorescent forms, the precise seat of the light-giving bodies, which he has dissected out again and again for the sake of making experiments in connection with this subject.

A more beautiful example of a phosphorescent mollusc is presented by a sea-slug called *Phyllirhoë bucephala.* This is a creature of from one-and-a-half to two inches in length, without a shell in the adult stage, and without even gills. It breathes only by the general surface of the body. It is common enough in the Mediterranean, but is not easy to see, as it is almost perfectly transparent, so that it cannot be distinguished without difficulty, by day at least, from the medium in which it swims. By night, however,

it is more easily discerned, in consequence of its property of emitting light. When disturbed or stimulated in any way, it exhibits a number of luminous spots of different sizes irregularly distributed all over it, but most thickly aggregated on the upper and under parts. These phosphorescent spots, it is found, are not on the surface, but for the most part represent so many large cells which form the terminations of nerves, and are situated underneath the transparent cuticle. The spots shine with exceptional brilliancy when the animal is withdrawn from the water and stimulated by a drop of ammonia.

Among the Annelid worms a species of *Nereis*, or sea-centipedes, has earned by its phosphorescent property the specific name of *noctiluca* (night-shining), and the same property is very beautifully shown in *Polynoë*, a near ally of the familiar sea-mouse. M. de Quatrefages speaks with enthusiasm of the beauty of the spectacle presented by this latter form when examined under a microscope magnifying to the extent of a hundred diameters. He then found, as he did in the great majority of cases which he studied, that the phosphorescence was confined to the motor muscles, and was manifested solely when these were in the act of contracting, manifested too, not in continuous lines along the course of the muscles, but in rows of brilliant points.

More interesting than the Annelids, however, are the Alcyonarian Actinozoa. The Actinozoa have already been described as formed on the type of the sea-anemone and the coral polyp, that is, they are all animals with a radiate structure, attached at one end, and having their only opening at the other end, which is surrounded by tentacles.

In the Alcyonarian forms belonging to this great group these tentacles are always eight in number, and fringed on both sides. Moreover, these forms are almost without exception compound. Like the Pyrosoma, they have a common life belonging to a whole stock or colony, as well as an individual life.

Now, throughout this sub-division of the Actinozoa phosphorescence is a very general phenomenon. Professor Moseley already quoted as a naturalist accompanying the *Challenger* expedition, informs us that "all the Alcyonarians dredged by the *Challenger* in deep water were found to be brilliantly phosphorescent when brought to the surface."

Among these Alcyonarians are the sea-pens mentioned in the quotation above made from Professor Martin Duncan. Each sea-pen is a colony of Alcyonarians, and the name is due to the singular arrangement of the individuals upon the common stem. This stem is supported internally by a coral rod, but its outer part is composed of fleshy matter belonging to the whole colony. The lower portion of it is fixed in the muddy bottom of the sea, but the upper portion is free, and gives off a number of branches, on which the individual polyps are seated. The whole colony thus has the appearance of a highly ornamental pen.

There is one British species, *Pennatula phosphorea*, which is found in tolerably deep water, and is from two to four inches in length. The specific name again indicates the phosphorescent quality belonging to it. When irritated, it shines brilliantly, and the curious thing is that the phosphorescence travels gradually on from polyp to polyp, starting from the point at which the irritation is applied. If the

lower part of the stem is irritated, the phosphorescence passes gradually upwards along each pair of branches in succession; but if the top is irritated the phosphorescence will pass in the same way downwards. When both top and bottom are irritated simultaneously two luminous currents start at once, and, meeting in the middle, usually become extinguished there; but on one occasion Panceri found that the two crossed, and each completed its course independently of the other. Those of our readers who have had opportunities of making or seeing experiments with the sensitive plant (*Mimosa pudica*) will be reminded of the way in which, when that plant is irritated, the influence travels regularly on from pinnules to pinnules and pinnæ to pinnæ.

In all the cases mentioned the phenomenon of phosphorescence is exhibited by invertebrate animals; but though rare, it is not an unknown phenomenon even in living vertebrates. In a genus of deep-sea fishes called Stomias, Günther mentions that a "series of phosphorescent dots run along the lower side of the head, body, and tail." Several other deep-sea fishes, locally phosphorescent, seem to have been dredged up by the French ship *Talisman* in its exploring cruise off the west coast of Northern Africa in 1883. During the same expedition, a number of deep-sea phosphorescent crustaceans were dredged up, the phosphorescence being in some cases diffused over the whole body, in other cases localised to particular areas. In deep-sea forms the phenomenon is, in fact, so common, as to have given rise to the theory that in the depths of the ocean, where the light of the sun cannot penetrate, the phos-

phorescence of various organisms diffuse a light which limits the domain of absolute darkness.

So much by way of illustration regarding the phosphorescence exhibited by animals, terrestrial and marine; but it ought to be noticed that there are also a few cases in which the same phenomenon is to be witnessed in plants. These are not so numerous as was at one time supposed, the property having been mistakenly ascribed to some plants not really luminous.

In some instances the mistake appears to have been due to a subjective effect produced by brilliantly coloured (red or orange) flowers, such as the great Indian cress, the orange lily, the sunflower, and the marigold. The fact that such flowers do give out in the dusk sudden flashes of light has often been stated on the authority of a daughter of Linnæus, subsequently backed by the assertions of various other observers. But most careful observers seem to be agreed that the supposed flashes of light are in reality nothing else than a certain dazzling of the eyes.

In another case, in which a moss, *Schistostega osmundacea*, has been stated to be phosphorescent, the effect is said to be really due to the refraction and reflection of light by minute crystals scattered over its highly cellular leaves, and not to be produced at all where the darkness is complete.

Among plants, genuine phosphorescence is to be found chiefly in certain fungi, the most remarkable of which is *Rhizomorpha subterranea*, which is sometimes to be seen ramifying over the walls of dark damp mines, caverns, or decayed towers, and emitting at numerous points a mild

phosphorescent light, which is sometimes bright enough to allow of surrounding objects being distinguished by it. The name of "vegetable glow-worm" has sometimes been applied to this curious growth.

Among other phosphorescent fungi are several species of Agaricus, including the *A. olearius* of Europe, *A. Gardneri* of Brazil, and *A. lampas* of Australia, and besides the members of this genus, *Thelaphora cærulea,* which is the cause of the phosphorescent light sometimes to be seen on decaying wood—the "touchwood" which many boys have kept in the hope of seeing this light displayed. The milky juice of a South American Euphorbia (*E. phosphorea*) is stated by Martins to be phosphorescent when gently heated. But phosphorescence is evidently not so interesting and important a phenomenon in the vegetable as it is in the animal kingdom.

The whole phenomenon is one that gives rise to a good many questions which it is not easy to answer, and this is especially true in the case of animal phosphorescence. What is the nature of the light? What are the conditions under which it is manifested? What purpose does it serve in the animal economy?

As to the nature of the light, the principal question is whether it is a direct consequence of the vital activity of the organism in which it is seen, of such a nature that no further explanation can be given of it, any more than we can explain why a muscle is contracted under the influence of a nerve-stimulus; or whether it is due to some chemical process more or less analogous to the burning of a candle.

The fact of the luminosity appearing to be in certain

cases directly under the control of the creature in which it is found, and the fact of its being manifested in many forms, as M. de Quatrefages found, only when muscular contraction was taking place, would seem to favour the former view. On the other hand, it is against this view that the phosphorescence is often found to persist after the animal is dead, and even in the phosphorescent organs for a considerable time after they have been extracted from the body of the animal. In the glow-worm the light goes on shining for some time after the death of the insect, and even when it has become completely extinguished it can be restored for a time by the application of a little moisture. Further, both Matteucci and Phipson found that when the luminous substance was extracted from the insect it would keep on glowing for thirty or forty minutes.

In *Pholas* the light is still more persistent, and it is found that when the dead body of this mollusc is placed in honey, it will retain for more than a year the power of emitting light when plunged in warm water.

The investigations of recent years have rendered it more and more probable that the light exhibited by phosphorescent organisms is due to a chemical process somewhat analogous to that which goes on in the burning of a candle. This latter process is one of rapid oxidation. The particles of carbon supplied by the oily matter that feeds the candle become so rapidly combined with oxygen derived from the air that a considerable amount of light, along with heat, is produced thereby. Now, the phenomenon of phosphorescence in organic forms, whether living or dead, appears also to be due to a process of oxidation, but one that goes on much

more slowly than in the case of a lighted candle. It is thus more closely analogous to what is observed in the element phosphorus itself, which owes its name (meaning "light-bearer") to the fact that when exposed to the air at ordinary temperatures it glows in the dark, in consequence of its becoming slowly combined with oxygen.

At one time it was believed that the presence of oxygen was not necessary to the exhibition of phosphorescence in organic forms, but it has now been placed beyond doubt that this is a mistake. Oxygen has been proved to be indispensable, and hence we see a reason for the luminous organs in the glow-worm being so intimately connected, as above mentioned, with the air-tubes that ramify through the insect.

This fact of itself might be taken as a strong indication of the chemical nature of the process to which phosphorescence is due. But the problem has been made the subject of further investigations which have thrown more light upon it. It was long known that there were various inorganic bodies besides phosphorus which emitted a phosphorescent light in the dark, at least after being exposed to the rays of the sun; but it was not till quite recently that any organic compound was known to phosphoresce at ordinary temperatures.

This discovery was made by a Polish chemist, named Bronislaus Radziszewski, who followed it up with a long series of experiments on the phosphorescence of organic compounds, by which he was able to determine the conditions under which that phenomenon was exhibited. In all the substances investigated by him in which phos-

phorescence was produced, he found that three conditions were essential to its production: (1) that oxygen should be present; (2) that there should be an alkaline reaction in the phosphorescing mixture—that is, a reaction such as is produced on acids and vegetable colouring matters by potash, soda, and the other alkalies; and (3) that some kind of chemical action should take place.

He found, moreover, that among the organic compounds that could be made to phosphoresce under these conditions were nearly all the fixed and ethereal oils. With reference to the phosphorescence of animals, this observation is important, for it has been shown in a great many cases that a fatty substance forms the main constituent in their luminous organs. This has long been known to be the case in the luminous insects belonging to the Lampyridæ and Elateridæ, as well as in the luminous centipedes; and the researches of Panceri, already referred to, on the luminous organs of many marine forms have shown that it holds good with regard to these also.

We may, therefore, conclude that substances fitted to phosphoresce under the conditions determined by the experiments of Radziszewski are generally, and probably universally, present in the luminous organs of phosphorescent animals. Now, what is to be said as to the occurrence of these conditions? The access of oxygen is in all cases easy to account for, but it must also be shown how the alkaline reaction is to be produced. We need not expect to find in animal organisms potash, soda, ammonia, and the other common alkalies; but it was established by experiment that the alkaline organic compounds cholin and

neurin, which are present in animal tissues, would also serve to bring about the phenomenon of phosphorescence in the substances on which the experiments were made.

Accordingly, it seems fair to conclude that when all these conditions for the production of phosphorescence in a chemical laboratory are present in animal organisms, the phenomenon, when observed in these, is exactly of the same nature as that which is produced artificially. By that it is meant that animal phosphorescence is attended, like the artificial phenomenon, by a slow chemical action, or in other words, that the phosphorescent light is due to a gradual process of oxidation.

One curious circumstance has been discovered which lends still further probability to this explanation. It was mentioned above that among phosphorescent plants there are several species of Agaricus. Now, from one species of this genus, though not indeed one of the phosphorescent species (from *A. muscarius*), there has been extracted a principle called *amanitia*, which is found to be identical with cholin. In the light of the results derived from the investigations just referred to it is reasonable to draw the conclusion that, if sought for, this principle would likewise be found in the phosphorescent species in which the other conditions of phosphorescence are also present.

On this theory of the production of the phenomenon now under consideration, the effect of shaking or of vital action in giving rise to or intensifying the exhibition of the light is accounted for by the fact that by these means fresh supplies of oxygen are brought into contact with the phosphorescent substance. The effect of ammonia on the

light emitted by the sea-slug, *Phyllirhoë bucephala*, is also fully explained, ammonia being one of those alkaline substances which are so directly favourable to the exhibition of the phenomenon.

Nor is it difficult to account for the control which in some cases insects appear to have over the luminosity of the phosphorescent organs, exhibiting and withdrawing the light at will. It is not necessary to suppose that this is an immediate effect, a conversion of nerve force into light, and a withdrawal of that force. The action of the creature's will may be merely in maintaining or destroying the conditions under which the light is manifested. It may, for example, have the power of withdrawing the supply of oxygen, and this supposition receives some countenance from the observation above cited from Kirby and Spence on the two captured glow-worms, one of which withdrew its light, while the other kept it shining, but while doing so had the posterior extremity of the abdomen in constant motion. But the animal may also have the power in another way of affecting the chemical conditions of the phenomenon. It may, for example, have the power of increasing or diminishing by some nervous influence the supply of the necessary alkaline ingredient.

But if animal phosphorescence is really due to a process of slow oxidation, there is one singular circumstance to be noted in connection with it. Oxidation is a process that is normally accompanied by the development of heat. Even where no light is produced an increase of temperature regularly takes place when substances are oxidised. We ought, then, to expect such a rise of temperature when

light is emitted by the phosphorescent organs of animals. But the most careful observations have shown that nothing of the kind can be detected. It was with a view to test this that Panceri, as above stated, dissected out the luminous organs of so many specimens of *Pholas*. He selected this mollusc because it was so abundant in the neighbourhood of Naples, where his experiments were made; and in making his experiments he made use of a thermopile, an apparatus by which, with the aid of electricity, much smaller quantities of heat can be indicated than by means of the most delicate thermometer. The organs remained luminous long after they were extracted, but no rise of temperature whatever could be found to accompany the luminosity. Many experiments upon different animals were made with similar negative results by means of the thermometer.

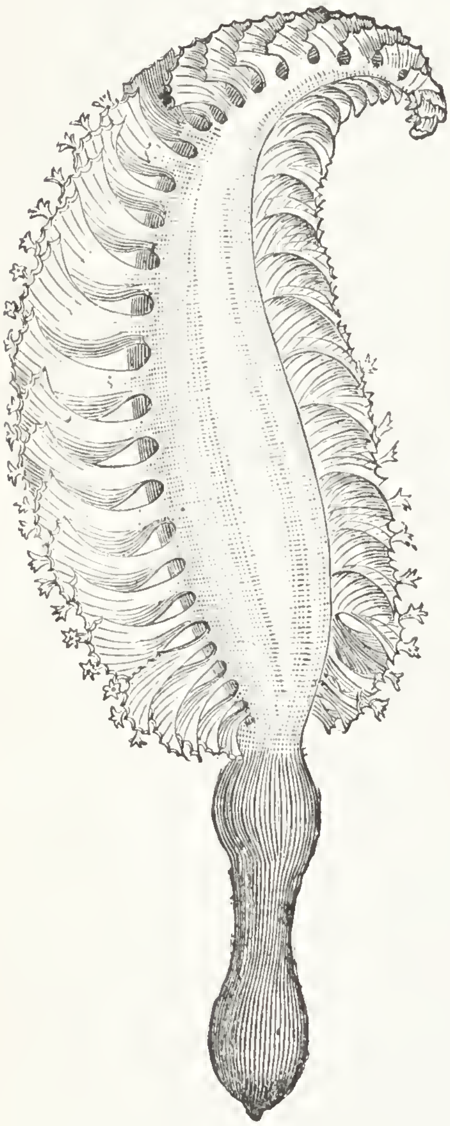

FIG. 6.—A SEA-PEN.

The only explanation of this that can be given is probably to be found in the fact that the chemical process ascertained to go on in the phosphorescence of organic compounds on which experiments were made in the laboratory is an extremely slow one.

The so-called phosphorescence of most inorganic bodies is one of a totally different nature from that exhibited in organic forms. The diamond shines for a time in the dark after it has been exposed to the sun; so do pieces of quartz when rubbed together, and powdered fluor spar when heated shines with considerable brilliancy. Various artificial compounds, such as sulphide of calcium (Canton's phosphorus, as it is called from the discoverer), sulphate of barium (Bologna stone, or Bologna phosphorus), sulphide of strontium, &c., after being illuminated by the rays of the sun, give out in the dark a beautiful phosphorescence, green, blue, violet, orange, red, according to circumstances. The luminous paint which has recently attracted so much attention is of the same nature. In these cases what we have is either a conversion of heat rays into light rays (as in the powdered fluor-spar), or the absorption and giving out again of sun-rays. In the latter case the phenomenon is essentially the same as fluorescence, in which the dark rays of the solar spectrum beyond the violet are made visible.

But we must now return to the other questions that have been started in relation to phosphorescence in animals. There has been much speculation as to the object of this light, and to the purposes it serves in Nature. Probably no general answer can be given to this question. It is no doubt impossible to show why so many animals have been endowed with this remarkable property, but we may consider some of the effects which the possession of it has in different cases.

In the first place, it will undoubtedly serve in many cases to afford light to enable the animal to see by, and in

the Lampyridæ it would seem that the degree of luminosity is related to the development of the vision. In that family, according to the Rev. H. S. Gorham, the eyes are developed, as a rule, in inverse proportion to the luminosity. Where there is an ample supply of this kind of light the eyes are small, but where the light is insignificant the eyes are large by way of compensation. And moreover, where both eyes and light are small, then the antennæ are large and feathery, so that the deficiency in the sense of sight is made up for by an unusual development in the organs of touch.

But it is none the less certain that the presence of this light cannot always be designed to serve this purpose, for many of the animals so endowed are blind. The phosphorescent centipedes are without eyes, like all the other members of the genus (*Geophilus*) to which they belong, and probably the majority of phosphorescent marine forms are likewise destitute of organs of sight.

Another suggestion is that the light derived from these marine forms, and especially from deep-sea Alcyonarians, is what enables the members of the deep-sea fauna that are possessed of eyes (which are always enormously enlarged) to see. Such is the suggestion of Dr. Carpenter, Sir Wyville Thomson, and Mr. Gwyn Jeffreys, and it is possible that this actually is one of the effects of the phosphorescent property. But if so, it remains to inquire how the forms endowed with it came to be possessed of a power useful in that way to other forms but not to themselves. According to the Darwinian doctrine of development, the powers that are developed in different organisms by the process of

natural selection are such as are useful to themselves and not to others, unless incidentally.

This consideration has led to another suggestion, namely, that the property of phosphoreseence serves as a protection to the forms possessing it, driving away enemies in one way or another: it may be by warning them of the fact that they are unpalatable food, as is believed to be the case with the colours of certain brilliantly-coloured caterpillars, it may be in other ways. In Kirby and Spence one case is recorded in which the phosphorescence of the common phosphoreseent centipede (*Geophilus electricus*) was actually seen apparently to serve as a means of defence against an enemy. "Mr. Shepherd," says that authority, "once noticed a carabus running round the last-mentioned insect when shining, as if wishing, but afraid to attack it." In the case of the jelly-fishes, it has been pointed out that their well-known urticating or stinging powers would make them at least unpleasant, if not dangerous, food for fishes, and that consequently the luminosity by which so many of them are characterised at night may serve at once as a warning to predatory fishes and as a protection to themselves. The experience of the unpleasant properties of many phosphorescent animals may likewise have taught fishes to avoid all forms possessing this attribute, even though many of them might be quite harmless.

Lastly, it has been suggested that the phosphorescence in the female glow-worm may be designed to attract the male; and that it will actually have this effect may readily be taken for granted. Observation shows that the male glow-worm is very apt to be attracted by a light. Gilbert

White, of Selborne, mentions that they, attracted by the light of the candles, came into his parlour. Another observer states that by the same light he captured as many as forty male glow-worms in one night, and the story above quoted from Peter Martyr indicates how the West Indian fire-fly may be caught by the same allurement.

MINUTE ORGANISMS.

By Frederick P. Balkwill.

Amongst the lowest group of the animal kingdom, which is called Protozoa—from the Greek *protos*, first, and *zoön* animal—are the Foraminifera—Latin *foramen*, a hole, *fero*, I carry—so named by M. d'Orbigny in 1825, on account of the shells which they inhabit being punctured with minute holes. At that time only a few of the many-chambered species were known as such, and they were supposed to be molluscs of the same character as oysters and cockles, and the animals whose handsome shells adorn our mantelpieces. These, however, are much more highly organised; they belong to the sub-kingdom of soft-bodied animals called Mollusca, from the Latin *mollis*, soft, and have nerves, blood-vessels, and a stomach, of which the Foraminifera are destitute, in common with the entire sub-kingdom Protozoa, to which they belong. They are, in fact, minute masses of a jelly-like substance, called sarcode—Greek *sarx*, flesh, and *eidos*, form—or protoplasm—Greek *protos*, first, *plasma*, workmanship—because it is the material of which and by which all living cells, animal or vegetable, are produced, whether these in turn go to form wood or bark, or build up the substance of bone or muscle, nerve or brain. These lowly animals, then, are little masses of protoplasm, which cover themselves with a shell usually punctured with fine holes, *foramina*, and

having one or more larger apertures; through all these holes the protoplasm protrudes itself in long hair-like threads, called pseudopodia—Greek *pseudos*, false, and *pous*, foot. These threads extend to a distance of several times the length of the shell; wherever they come in contact with each other they adhere, and unite to form a living network, and along the various lines of this net the granular matter of the protoplasm freely flows; thus a circulation of granules is carried on, not in veins and arteries, as in the higher animals, but on the outside of an adhesive or viscous network in the medium of salt water. Whenever any food touches this net it adheres to it, more protoplasm flows over and embeds it, the nutriment is absorbed, and the refuse is ultimately rejected. This nourishment goes on outside the shell. The animal can protrude or retract these threads, which seem to possess the sensibilities of life at least in some degree; for whilst the animal has no proper organs of sight, feeling, digestion, or locomotion, such as eyes, fingers, stomach, or feet, any part of the net can feel, seize, and digest its food, can enable it to crawl about, and if separated by being cut off, no sooner touches any portion of the net than it unites with it immediately.

How different from the wonderful and complex organisation of man—separated from him by the breadth of the whole animal kingdom! Yet these lowly living things have been peopling the oceans and the rocks with myriad forms of marvellous beauty, from the earliest period of which we have any record of life upon the earth down to the present time. We can now understand why they are called also Reticularian Rhizopoda. The "Rhizopoda"—

Greek *rhiza,* a root—is the division of Protozoa comprising those animals which are capable of emitting pseudopodia, and "Reticularia"—Latin *reticulum,* a net—those in which the pseudopodia run into one another and form a network. The shells are mostly composed of carbonate of lime, and form a large portion of our chalk and limestone rocks; some are built up of grains of sand cemented together. These are mostly siliceous; some shells are membranous, or chitinous—Greek *chiton,* a coat; chitine is the horny elastic substance of beetles' wings, or the coating of shrimps and crabs. In a very few localities where the depth is great—from 2,500 to 4,000 fathoms—we are told by H. B. Brady, F.R.S., the carbonate of lime in a few Milioline shells is replaced by clear homogeneous silica, or flint. The walls are delicately thin, so thin that the shell sometimes collapses on being taken out of the fluid and allowed to dry; it is opalescent, or nearly transparent, and when quite fresh, iridescent.

The shells of the Foraminifera are of three principal structures, called respectively Porcellanous, of the texture of porcelain, Hyaline—Greek *hualos,* crystal—crystalline or glassy, and Arenaceous, made up of sand grains.

The porcellanous are white by reflected, but amber-coloured by transmitted light; they emit their pseudopodia in a branching trunk from one aperture, but their shells are not perforated by pores.

The hyaline are like glass when young, becoming white or semi-opaque with age, through the growth of shell-matter which converts the pores into tubules; sometimes portions of shells are permeated by minute tubules,

when these parts become bands or markings of white or partially opaque appearance in the otherwise clear transparent shell. These hyaline shells are perforated by larger or smaller pores, through which, as well as through their apertures, they emit pseudopodia.

The arenaceous tests—Latin *testa*, a shell—are made up of grains of sand, cemented together by altered protoplasm, much as broken pieces of glass may be cemented by the white of egg; these, as before mentioned, are of flint, not carbonate of lime; they are not porous, but, like the porcellanous shells, they emit their pseudopodia by one aperture in a trunk. There is, however, another kind of arenaceous shell, in which the shell substance is partially replaced by grains of sand; these are foraminated, and are often tinged orange or brown, the small first-formed chambers being darkest. These are probably coloured by the oxide of iron, or rust, which is intimately associated with animal and vegetable life everywhere.

Some of the Foraminifera are one-celled, or monothalamous—Greek *monos*, one, *thalamos*, chamber; except in these, the animal, as it grows, adds fresh chambers to its abode, each being generally larger than the preceding one, and formed around its aperture: thus from the first chamber to the last, each one opens into the next, and the creature inhabits them all, at the same time. In the more complex forms, there is a system of communicating canals which pervades the thickened walls of the various compartments of the shell (Fig. 1). If the shell be dissolved away, the animal will look like a string of beads.

Professor Ehrenberg discovered that these shells occa-

sionally undergo an infiltration of silicate of iron that completely fills their chambers and canal system, so that when a shell thus permeated is decomposed, a perfect cast remains of the original body of the animal, with its extensions throughout the shell. Of such casts the green sands—that present themselves in various formations, from the silurian, which is one of the oldest, downwards—are in great part composed; and it has been shown by Professor Bailey that a like process is now taking place over certain parts of the ocean bottom, and that beautiful internal casts are obtainable by treating with dilute acid shells thus filled — because the acid will dissolve and remove all the lime. By this plan Messrs. W. K. Parker and T. Rupert Jones obtained from some Australian dredgings a series of internal casts of great beauty and completeness.

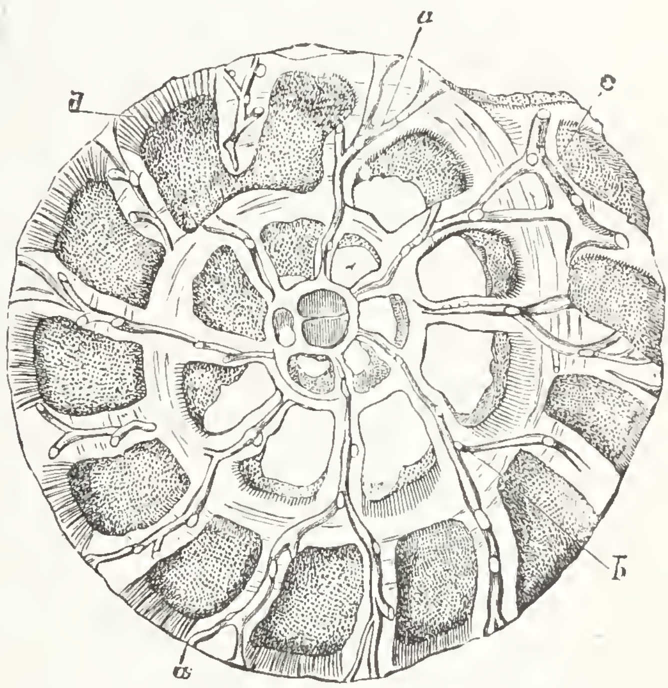

FIG. 1.—SECTION OF THE SHELL OF ROTALIA SCHRŒTERIANA, NEAR AND PARALLEL TO ITS BASE. (*After Williamson and Carpenter.*)

Showing—*a a*, the radiating interseptal canals; *b*, their internal bifurcations; *c*, a transverse branch; *d*, the tubiliferous wall of the chambers.

As regards reproduction, a few observers have noticed the protoplasm in several chambers of the shell alter its condition and contract into granular masses, which in time have given

rise to young, either as a minute one, two, or three-celled shell, or as ciliated spheroids swimming about. Dr. W. B. Carpenter mentions that Professor Max Schultze, in 1854, having obtained some large living Foraminifera of the genus *Miliolina*, kept them some time under inspection, and found that some of them, after adhering to the sides of the glass vessel from eight to fourteen days, became covered with a brownish slimy matter which obscured the view of the external characters of their shells. After some days, minute, sharply-defined granules could be seen in this substance with the aid of a lens; these gradually loosened themselves from the soft enveloping mass, and separated further and further from the shell which it surrounded. Microscopic examination of these little bodies—of which forty were counted round a single progenitor—proved that they were young *Miliolinæ*. When viewed by transmitted light, they presented a pale yellowish-brown calcareous shell, consisting of the central globular chamber, in which all foraminifera seem to commence, surrounded by a tubular part, not separated from the preceding by any distinct septum or partition. In a short time the animals put forth their pseudopodia from the aperture of the shell, and crawled about on the surface of the glass. It is very interesting to notice that these young *Miliolinæ*, not a hundredth part the size of their parent, which is oval and composed of alternate narrow chambers (Fig. 3), begin life as a tube bent round a circular chamber. This is precisely what another genus, *Cornuspira* (Fig. 2), continues to be through life, the tube coiling round it many times in one plane; the hyaline or perforated equivalent

to *Cornuspira* is *Spirillina*, and the finely arenaceous form, *Ammodiscus*.

This, by the evolution theory, would make *Cornuspira* the least-changed representative of the primitive type from which the porcellanous foraminifera may have been derived.

FIG. 2.
CORNUSPIRA INVOLVENS.

Professor Schultze has since observed a similar phenomenon in *Rotalia* (Fig. 4), which is about $\frac{1}{100}$th of an inch in diameter. On breaking the chambers, twenty or thirty young forams were found within them : these consisted of three nearly equal globular chambers mutually adherent, the first and innermost being the largest. On watching other individuals which presented a similar granular appearance in their contents to that exhibited in the specimen before mentioned, a multitude of granules suddenly appeared in their neighbourhood, which proved to be young. J. D. Siddall watched some fine living specimens of a very common foraminifer of our shores—*Polystomella striato-punctata*—under the microscope; he says : "They were for a few days particularly active, and crawled about the cells in which they were placed for examination. At the end of that time the pseudopodia of some became finally retracted, and the sarcode showed a tendency to become granulated and condensed into an oval mass in the centre of each chamber of the shell." "Twelve chambers of the shell were visible externally. The granular oval contents of chambers Nos. 2, 4, and 9, from the aperture, were furnished with cilia distinctly apparent with a power of 400 diameters, and

swam freely about in the chambers ; on the contents of the other chambers no cilia were visible, and the form assumed by the contracted sarcode was not so definite." "This formation of ciliated spheroids of sarcode within the chambers of the parent shell no doubt represented the earliest stages of one kind of reproduction of the species. And the probability is, that, on the breaking up of the shell the spheroids would be liberated, and live for some time in the free swimming condition, then absorb their cilia, settle down, and secrete a shell, and become the primordial chamber of a form like the parent."

As, however, there does not appear to be evidence that these shells do break up, but, on the contrary, that their structure renders them very permanent, and as Schultze, who did break up one shell, found that the young escaped rapidly from shells that were not broken, it would appear that the ordinary apertures which open from chamber to chamber, and lastly into the surrounding medium, are sufficient for the young, whether as one or three-chambered shells, or ciliated spheroids, to escape by. These apertures are probably closed by the protoplasm in the course of the breaking up of the parent, in the granulating process, and are then opened again, when that process has been completed, and the young are sufficiently developed to be ready to escape. Those who have studied botany will recognise several analogous developments from protoplasm in the vegetable kingdom. For instance, in the "cambium layer," where the sap rises in spring between the bark and wood of trees to form new tissue; in the embryo sac, the cell in the apex of ordinary seeds whilst in the condition of unde-

veloped ovules, where, after contact with the "pollen tube" communicating the male influence, the protoplasm breaks up into free granules, which form new cells, that, joining together, build up in the seed the germ of the new plant; and among the seaweeds, where ciliated spheroids are produced and liberated. In fact, the origin or beginning of life is very similar everywhere. We are not yet aware, however, of any observations concerning conjugation among the Foraminifera. Any one who has watched with a powerful magnifying-glass the eggs of a flat spiral shell, called "planorbis," and noticed the growth of the shell within the transparent egg on the glass side of a fresh-water aquarium, will note the close resemblance between the development of these and that of the much lowlier animals in the description of the *Miliolina* by Professor Schultze.

In examining a flat one-celled foraminifer, named *Lagena lagenoides*—Latin *lagena*, a flask—we noticed in its interior four flat oval bodies, which at first suggested the idea of young. On applying a higher magnifying power, however, the surface of each was discovered to be crowded with the familiar rows of dots on the flint shells of diatoms; these rows (though much closer) were arranged like the lines of longitude and latitude on a flat map of the globe. The name of this diatom is *Cocconeis scutellum*.

What is remarkable about this is, that a fine tube projects from the small circular aperture into the chamber of the foram to about one-third its length, and the diatoms could not have passed through it in their present size,

being in their narrowest diameter fully twice that of the tube. The probability seems to be, that they got in when much smaller, and grew there by feeding upon the substance of the dead foraminifer. This theory is not without difficulty, however, as under ordinary circumstances foraminifera feed upon diatoms, though outside their shells; we must suppose, therefore, that the digesting power of the foraminifer was interfered with by some circumstance, possibly such as the change induced prior to producing young, or that the diatoms were in such a condition—as germs—as to be able to resist and overcome the digestive power of the foraminifer; the former supposition seems more probable. We were much chagrined that, whilst drawing it by the camera lucida, the slide containing this specimen fell against the microscope, and the shell was smashed.

The Foraminifera are distributed very abundantly in the coralline areas of our warmer seas; a few species are confined to these waters, and add to the evidence to be gathered from other fossil types, that the rocks in which they occur were once covered by the tropical or sub-tropical waters of a similar coral zone. The deep ocean bottom has yielded great abundance, and many species have been found even in Arctic waters. In the bottom of the Atlantic, in areas traversed by heated currents, is a deposit of Foraminifera closely allied to chalk—in fact, now forming the chalk rock of future ages. Some few species seem to prefer brackish water, and are found most plentifully where the salt water of the sea has been diluted by fresh water; some are more at home in the shallower

waters of our shores, such as the *Miliolinæ* (Fig. 3); some live in the surface waters of oceans, where they may be captured alive by the tow-net, and whose shells sink at last to the abysmal depths below, such as the *Globigerinidæ*. The waters around the coasts of the British islands are prolific of foraminiferal life, and the rocks tell us that this life has been equally abundant in seas of the long hoar past. In the oldest stratified rocks with which we are acquainted is a fossil supposed to be a foraminifer (*Eozoon Canadense*), and so, from the earliest appearance of life on our planet down to the present time, immense quantities of these shells occur. In the secondary rocks Foraminifera occur in great abundance. Chalk is, in fact, almost entirely composed of their broken shells, and the chalk powder to be found in cavities of large flint nodules, known as "Paramoudras," contains the siliceous "casts" of the Foraminifera which have been already described; among these, *Textularia globulosa* is very plentiful. In the Tertiary rocks, or those of later formation, the Foraminifera attain a full development in size, and in the variety of forms which characterise them; and one kind of limestone, belonging to the "Middle Eocene"—or the earlier portion of the Tertiary rocks—is called nummulitic limestone, from the quantity of a large circular foraminifer which it contains, named "Nummulites"—Latin *nummus*, money.

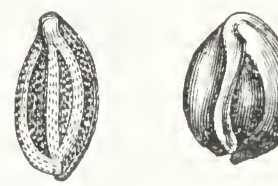

FIG. 3.—RECENT MILIOLINÆ.

These nummulites are nearly an inch in breadth, and the nummulitic limestone stretches from Europe to China,

and is remarkable for forming that platform of rock upon which the Great Pyramid of Egypt was built. This large foram, as well as its representatives of a similar size in our tropical seas, is composed of a very large number of segments, arranged in a spiral or circular manner. One of these modern forms, called *Orbitolites*—Latin *orbis*, a circle—has the power of replacing broken portions of the shell, even when numerous chambers have been destroyed, and has a very complete canal system.

The shores and seas of Great Britain and Ireland abound with a large variety of these beautiful shells, as do many deposits of salt-water mud and fine sand of the formation following the Tertiary Rocks, and called Post-tertiary; these are the estuarine and boulder clays, not yet hardened into rock; and when such clays have been examined, they have yielded Foraminifera having all the freshness in appearance of recent shells; indeed, they present very little difference of any kind from such. In the estuarine clay from Limavady station, Lough Foyle, Joseph Wright, F.G.S., found ninety-eight species, nearly identical with fresh, recent species, and all but two now found off our coasts; of these two, one was *Ramulina lævis*, and F. W. Millett, F.R.M.S., has since found a Ramulina in some shore gatherings from Galway.*

Any one who has a microscope that will magnify from 30 to 100 diameters—that is to say, having an object-glass of from two-inch to one-inch focal distance—will find it exceedingly interesting to collect, prepare, examine, and mount for himself, these tiny works of the All-wise

* "The Foraminifera of Galway," *Journal of Microscopy*, Vol. III.

Creator, from his own neighbourhood; and the labour will be amply repaid. Does he live in London? Some scientific friend could put him in the way of getting the right sort of blue London clay to soak and wash out; if in the country, some "estuarine" or "boulder clay"; but when at the sea-side, a few pints of carefully-selected sand would afford occupation and interest for months after returning home; and if there is an opportunity for dredging a mile or two off the land so much the better.

We will now take our way to the shore, having provided ourselves with two or three small bags for our spoil, an iron spoon, and a good "Coddington" lens—which will magnify about thirty diameters, and will show most of the British foraminifera quite distinctly.

Here is a broad expanse of sand, and it is nearly low tide. We will first examine the high water line, not exactly amongst the coarser seaweeds—though, if there seems to be any promising-looking shelly matter beneath them, we may examine it—but where the receding waves have left white ripple marks in curved lines on the fine hard sand, and where the drainage of the sand has left similar deposits behind. Sometimes the deposit is, however, very considerable, both in extent and thickness; when this is the case, the number of species will probably be few. We take a scraping with our spoon—or a razor-shell if within reach—and look at the surface particles with our Coddington lens. Ah! here is an oval shell like a sugared almond, polished and marked lengthwise into two or three chambers. It is a *miliolina;* it is oval in shape and round at the edges: these characteristics de-

termine it to be *Miliolina seminulum.* Here is another; this is larger and broader than the last; it is very thin, with sharp edges, and there are fine curved lines—"striæ"—across the chambers; this is *Miliolina secans.* Here is a small nautilus-like shell; it has not, however, a large mouth in front, like the nautilus, but, instead, there is a convex face of shell, which forms the front wall of the last chamber. All the other chambers have similar convex fronts; these are partitions covered by the sides of the shell, and are indicated on the surface by curved rows of bars, or holes, of which about twelve rows are visible at once, springing from a common centre; both sides are alike. This is *Polystomella striato-punctata;* had the edge been sharp, armed with spines, the bar-like markings commencing at one chamber-wall, and losing themselves before arriving at the next, it would have been *Polystomella crispa,* probably the most highly organised of our British species, as it is permeated by a canal system, of which these bar markings form part, and it has an internal skeleton. As the animal grows it gradually covers the earlier chambers by other and more numerous ones, which extend to or include the spines, and the number of chambers in the spire is increased.

If we have a shell like *Polystomella striato-punctata,* that is, with round edges, but the rows of perforations replaced by curved lines, it is *Nonionina depressula.* If such a shell have chambers arranged in two or three turns of a spire on one side only, it will be *Rotalia Beccarii* (Fig. 4), unless it is brown, with a red centre, when it will be *Trochammina inflata,* and we are near some

fresh-water streamlet or river, which has diluted the saltness of its habitat, or home. *Discorbina globularis* is another common littoral species, which will be easily recognised by its swollen chambers and large pores. Having satisfied ourselves that we have these shells, we put some "scrapings" into our bag, and move on towards the sea; we only stop to pick up a few corallines, and to take a spoonful here and there from the bottom of the little hollows in the sand. Sometimes these are quite dry, but occasionally, as one approaches low-tide mark, they are full of water, and one needs waterproof boots and trousers. Still, with our iron spoon we make each hollow pay its tribute to our bag, taking as little sand as possible with the teaspoonful of half-floating sediment. In some places the ground is not so flat, and by the bank of a small stream, where the ebbing tide has left richer deposits, we take some scrapings with a razor-shell. In collecting thus from the shore, we select such accumulations as have been left by water, but avoid such as have been drifted by the wind; for the wind, driving the dried light shells over the sand, makes them worthless as specimens through the surface wear; the finer sorts will be destroyed altogether, and the few large coarse species of which the drift is composed will be mostly broken. Of this character are the foraminiferal deposits of the sand dunes, where we have

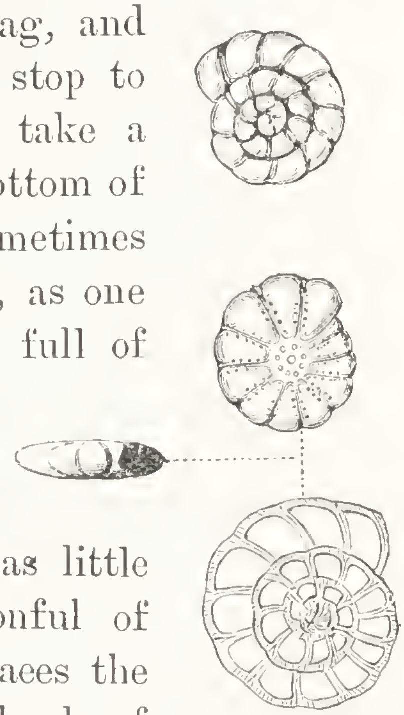

FIG. 4.—ROTALIA BECCARII.

collected pints of nearly pure *Miliolinæ* of one or two species, but all imperfect and worn.

Now for the rocky part of the shore, where there are sheltered half-tide pools; we collect a little first around the base of the rocks and large stones, where we shall probably find *Miliolina secans* and *Polystomella crispa*, already described; around the sides of these pools, both below and above the water edge, we scrape carefully, taking some of the mat of fine seaweed which is clogged with sand, and adheres closely to the rock. In this material we shall probably obtain the greatest variety of species, including some of the most lovely and delicate forms, such as *Lagena Lyellii*, and *Haplophragmium canariense*. Having thus loaded ourselves, and if we wish to be very systematic, having our bags numbered, and reserving one each for high tide, for low tide, and for the material from the half-tide pools, we next, on reaching home, wash away the salt and mud, if there be any with the fine sand. This mud—or ooze, as it is called—has some of the smallest species in it, such as *Globigerina bulloides*, a spiral shell of globular segments, and *Bulimina elegantissima*, which reminds one of the twisted petals—"convolute"—of the mallow or the flax when in bud.

In washing, we may reject any particles less than $\frac{1}{200}$th of an inch in diameter, not because they are destitute of foraminifera, but because there will be larger specimens of all thus lost in our washed sand; we must also separate the weed and corallines, stones, or broken shells. For these purposes we employ two sieves. A coarse one, of perforated zinc with holes about one-eighth of an inch in diameter,

through which wash the sand and foraminifera out of the weed into a fine sieve below, by turning on it water from a tap. The fine sieve—a linen handkerchief will do—is either of brass wire or silk gauze; if the former, it has 120 wires to the inch; if the latter, 180 threads, such as is used for sifting flour by millers. Wash a cupful at a time. When free from salt, put the clean fine sand on a dish in the oven to dry. When dry and cold, stir it in water; the shells being full of air, will float; stir well, and pour the floatings into a small vessel, so as to wet the small particles of sand that they may sink, and pour off, on to a piece of silk gauze or a pocket handkerchief; when dried, these will be composed of foraminifera, minute shrimps or other small crustacea—crabs—which dwell in a double oval shell, and are called "Ostracoda"—Greek *ostrakodermos*, covered with a shell—and broken corallines; if dirty, boil in liquid potash, which will dissolve the soft animal and vegetable substances, and leave the shells, if composed of lime, clean. Having been boiled, the foraminifera will sink, being full of liquid; pour off the brown liquid, boil again with water, and wash all the potash well out, then dry the shells. Every one of them will now be exquisitely clean, and when sprinkled upon a piece of slate $3\frac{1}{2}$in. by $1\frac{5}{8}$in. for examination under the microscope, they will look like dust; yet, how many shells do you suppose are there? If the slate is well covered you have probably at least 10,000 specimens! and amongst these you will be able to identify from forty to ninety species.

Mr. Brady says that Professor G. O. Sars, of Christiania, speaks "of the northern deep water cold area," between

Norway, Spitzbergen, Iceland, and Greenland, at a depth of from 300 to 2,000 fathoms, temperature from 32° to 35° Fahr., and says:—"The sea bed consists of a soft mud of nearly uniform composition, that is to say, composed in very large proportion of one species of porcellanous Foraminifera—*Biloculina ringens*." H. B. Brady, in examining some of this "*Biloculina* mud," found about one half to consist of this species. He says, "The specimens of *Biloculina* are very uniform, they are of the stout, inflated typical form, with a small admixture of the depressed carinate variety, *B. depressa*." Here in the Irish Sea, at a depth of about 50 fathoms, the proportions were reversed, *B. depressa* being quite one half or more of the washed foraminifera, whilst there was a small admixture of *B. ringens*.

So also *Lagena costata*, which is the largest in diameter of our British *Lagenæ*, seems to take the place at this depth of the *Lagena Williamsoni* so common on our shores; this latter has about sixteen ribs, forming as many semi-circular depressions between them, and connected with the aperture by hexagonal reticulations. Both are balloon-shaped, but *L. costata* is not reticulated, and is grooved by furrows leaving gore-like spaces between them.

Joseph Wright, F.G.S., of Belfast, joined us in examining this mud, as well as shore-gatherings and dredgings of our own, on which we reported to the Royal Irish Academy in 1885.

On two occasions we secured muddy sand, about 5lb. in weight, taken from the jaws of a very peculiar fish, called by fisherman the "angler fish," *Lophius*

piscatorius—Greek *lophius*, a bristle; Latin *piscatorius*, fishing (Fig. 5). This fish, with a very large mouth, buries itself in the sand, and from its nose a bristle, like a rod and line, comes out and hangs in front of its mouth,

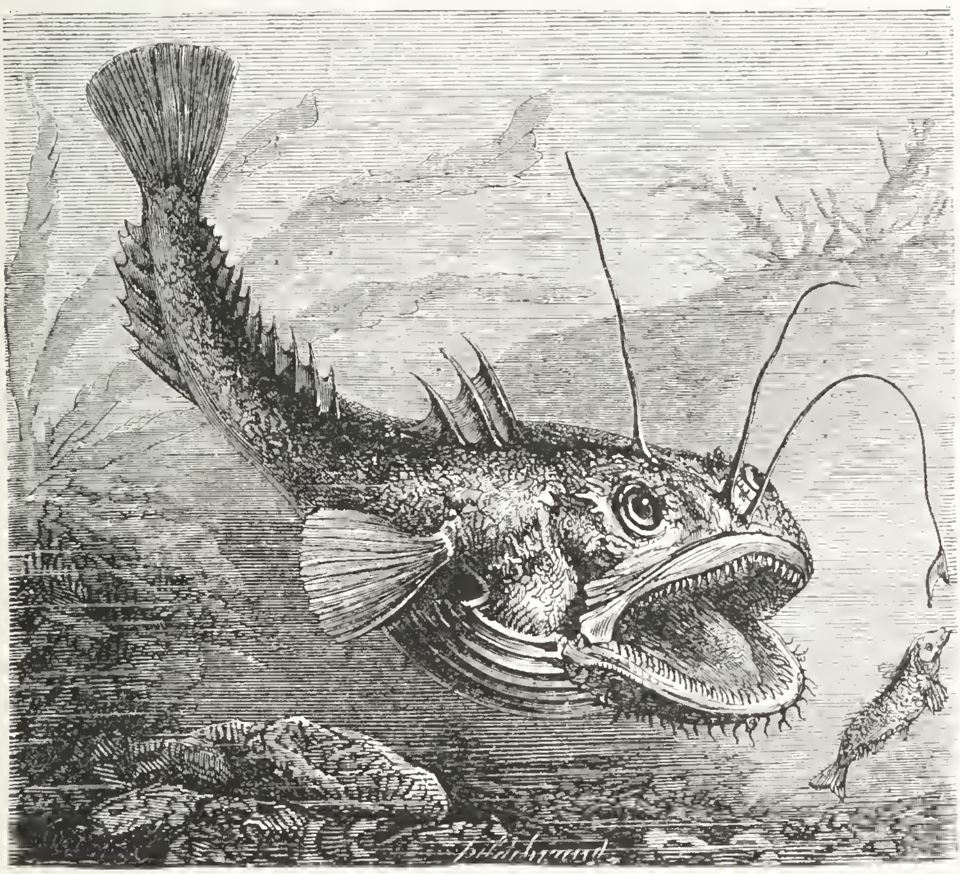

FIG. 5.—LOPHIUS PISCATORIUS.

while unseen, like the ant-lion, it awaits its prey. The fishermen say that when it gets in their nets "it drags through the sand with its mouth open," which thus gets filled with mud. However this may be, one taken about eighteen miles off Dublin, another near the Isle of Man, were remarkably rich in the finer and rarer sorts of Foraminifera, some being common in them which we

seldom found elsewhere. *Bulimina marginata* (Fig. 6) occurs plentifully, and also the more rare spinous variety, *Bulimina aculeata*, with every gradation of form between them.

Professor Williamson records that Mr. Hyndman of Belfast obtained a large number of specimens of *Polystomella striato-punctata*—Greek, *polus*, many, *stoma*, a mouth, because instead of one aperture there is a row of holes—from the stomach of a sheldrake shot in Belfast Bay, and these shells were unmixed with any other species of Foraminifera. How this species had been picked out and separated from other species is not clear. We found it by millions on the shores of Dublin Bay, but never unmixed; it may have constituted one-fourth of the foraminifera of some gatherings. In the "deep hole" of the Irish Sea, seventy fathoms, the porcellanous flat *Biloculina depressa*, as already mentioned, is so much more plentiful than any other species, that it seems to greatly outnumber all the rest put together, so it is with *Truncatulina lobatula* at Youghal, and at Gwembarra Bay; so we have found *Miliolina secans* at Malahide, where they lay on one occasion about half an inch thick for hundreds of yards, between the vessels and up to high-tide mark, these shore-results being probably caused by temporary circumstances, but such a thing as any species wholly unmixed we never found, so that they must have been selected by some small marine animal on which the sheldrake fed.

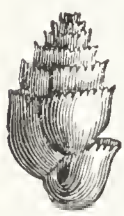

FIG. 6. BULIMINA MARGINATA.

In 1881 we had taken dredgings around Dublin Bay

from about five miles off the hill of Howth to the north, to eight miles off Bray Head to the south, some thirty dredgings in all; the greatest depth being twenty-six fathoms off Bray. The bottom had varied from fine sand with good results, to coarse sand with poor results, except that in Dalkey Sound, five fathoms water, just inside the little island of Dalkey; the sand, though coarse, yielded a large number of species: this was associated with a rapid flow of water in a sheltered little bay; and close by the rocks of Dalkey Island, Professor A. F. Haddon, of the Royal College of Science, Dublin, found specimens of a cornucopia-like foraminifer made of sponge spicules, *Haliphysema Tumanowiczii.*

Near a bank of sand called Bray Bank, about six miles off Bray, where the water shallows, from twenty, to three or four fathoms, we twice hauled up the dredge full of scallops, and once or twice we had large quantities of twisting sand stars, &c., but we were anxious to try the deeper sea, so, on the 7th of August, 1882, on board the fishing-boat *Maggie,* of sixty tons, with J. Wright, F.G.S., we started from Kingstown Harbour at 10 A.M. for "Lambay Deep," some fourteen miles from the shore towards the Isle of Man—an irregular oval patch on the chart—where the bottom was much deeper than the rest of the sea at that distance from the land. The day was fine and clear, but there was very little wind, and it was 1 P.M. before we, having taken one dredging, got clear of the Bailey Lighthouse at the extreme north of Dublin Bay, and dined on some freshly-caught fish. At 2 P.M. we passed a school of porpoises, a very pretty sight as they tumble

over in the water. We were becalmed, and drifted with the tide.

The dredge is a heavy four-sided iron frame sloping inwards and downwards, and so arranged as to scrape the bottom as it is dragged along. It opens into a strong net, which contains at its bottom a cloth or canvas bag which will hold two or three gallons. We had more than 150 fathoms of good strong line to let it down by. When dredging the bottom the strain on the rope is considerable. It was emptied on to a wooden tray; stones, shells, and weed being rinsed in a pail of water and rejected, the sand and mud, when the water had been poured off, being put into a numbered bag, and a record made of the locality of the dredging. For this purpose we had charts and compass, and took our bearings, besides having the experience of Capt. Voysey to go by, and it was a great advantage to have a fisherman with a good knowledge of the bottom.

The mud and sand obtained by this expedition amounted to about 3 cwt., and took a long time to examine. It proved highly interesting, especially the specimens from the deep water. Amongst these may be mentioned three arenaceous forms, so heavy that they would not float:—*Haplophragmium pseudospirale*, a broad flat shell $\frac{1}{16}$ of an inch long, by $\frac{1}{48}$ of an inch in breadth—this is irregularly built up of coarse grains of sand, beginning with a spiral and then lengthening out like a short broad bean. *Hyperammina elongata*, a nearly straight tube, $\frac{1}{10}$ of an inch long by $\frac{1}{80}$ of an inch in breadth; and *Reophax scorpiurus*, $\frac{1}{20} \times \frac{1}{60}$, roughly egg-shaped, but more pointed, and having the commencement slender and slightly bent. It has a

round opening at the broad end, and the interior is not divided by partitions, though somewhat narrowed twice. It looks like a crystalline grotto, of which the inside of a "potato stone," which contains crystals of fluor spar, would give some idea; the outside looks like a piece of gum arabic with a few black specks in it.

Amongst the specimens which floated, perhaps the most remarkable was *Cornuspira foliacea*, which, beginning as a very fine tube coiling on itself, after about six or seven convolutions, suddenly increases in size very rapidly, and broadens out, until in two or three turns more, it becomes a bold and beautiful shell, flat as a worn sixpence—$\frac{1}{16}$ of an inch across. They were very fragile, the centre easily breaking out of the shell. Another remarkable species found here was *Marginulina glabra*. This is usually composed of four or five cylindrical chambers in a slightly-curved row, with oblique partitions, the last chamber much swollen on the inner side; but these were much larger—of six chambers, $\frac{1}{14}$ to $\frac{1}{10}$ of an inch in length—nearly straight, and the peculiarities mentioned above reduced to a minimum; there could be no doubt whatever as to their identity, as they formed very decidedly but one species, and every now and then we came across a typical example.

The classification of Foraminifera can hardly be said to be yet satisfactorily settled, the simplest perhaps is that of Carpenter, Parker, and Jones. They divide the order Foraminifera into two sub-orders, depending upon the character of the shell, those not porous, or "Imperforata," and those porous, or "Perforata," and each sub-order they divide into three families. There are, however, objections to this

arrangement, and H. B. Brady proposes eleven families, abandoning the sub-orders, as he retains among them the six families of Carpenter, Parker, and Jones, whilst reducing them. We will briefly allude to these.

Family 1.—*Gromidæ,* test not porous, chitinous.

Family 2.—*Lituolidæ,* test arenaceous, divisions imperfect.

Family 3.—*Miliolidæ,* test porcellanous, sometimes encrusted with sand.

Family 4.—*Lagenidæ,* test hyaline, built of egg-shaped compartments, each on the pattern of a Lagena, glassy, finely tubular.

Family 5.—*Globigerinidæ,* test hyaline, coarse, built up of globular compartments.

Family 6.—*Nummulinidæ,* test finely tubulated; all the higher types possessing a system of canals.

Of these, the last two families have remarkable characteristics, the *Globigerinidæ* being mostly found living in the open sea at or near the surface, of which our *Globigerina bulloides* may be taken as a type. The *Nummulinidæ* have an internal skeleton with a complex system of canals, all filled by the animal during life and well shown by the "casts" before described.

The *Lagenidæ* are very finely tubular, smooth, or with longitudinal ribbing or symmetrical ornamentation, the aperture usually has a circular lip with radiating fissures. These are derived by the addition of chambers of the same character from the type of a highly interesting genus called *Lagena,* which are one-celled and vary from a globular or egg-shape to a very long-necked spindle shape on the one hand,

and to a thin, flat, winged form on the other; some are like decanters, balloons, or soda-water bottles of delicate white glass. The extreme beauty and symmetry of these unique shells makes them universal favourites. They have great variety of form and ornamentation, and the apparent stability and persistence of some of these forms is indicated by the geologic record. At the same time, whilst the vast majority of some forms are true to type—such as *Lagena Williamsoni*—yet there are continually to be found intermediate forms linking these types together in such a way, that authorities have scarcely liked to decide, whether to call any of these diverse forms species, or only varieties. And this difficulty which meets us in the *Lagenæ* is to be found more or less throughout the entire order.

There has been some difficulty in deciding whether a few genera, which contain in their substance certain oval bodies called nuclei, ought to be included among the Foraminifera or not; but as "recent researches,* notably those of Professor R. Hertwig and Professor F. E. Schulze, have shown, that certain types of Foraminifera possess nuclei indistinguishable from analogous bodies in the chitinous fresh-water Rhizopods," and Professor Leidy, in his elaborate work upon the "Fresh-water Rhizopods of North America," treats "*Gromia* as a genus of Foraminifera," therefore, H. B. Brady, F.R.S., in his new classification of the order, makes *Gromidæ* its first family, in which he follows Dr. Carpenter,† Parker, and Jones.

* Notes on the Reticularian Rhizopoda of the *Challenger* Expedition by H. B. Brady, F.R.S. Part III. *Micr. Journ.*, Vol. XXI. New series, p. 6.

† *Ibid*, p. 11.

The Imperforate division of Foraminifera—that is, those whose shells have only one aperture through which the protoplasm issues, in a branching trunk to form its net-work—contains, besides some arenaceous or sandy foraminifera, which are more properly arranged without reference to this distinction, two families: 1st. *Gromidæ;* 2nd. *Miliolidæ.* Of the second family, which are porcellanous, we have already spoken; the *Gromidæ,* which include *Gromia, Lagynis, Lieberkühnia,* and *Shepheardella,* have a chitinous test or shell; this, which is normally elastic and horny, like a beetle's wing or a shrimp's shell, may vary from that to a mere membranous covering of hardened protoplasm. Dr. Carpenter gives an illustration of *Lieberkühnia Wageneri* very much the shape of a heart, between ovate and pear-shaped, with a trunk that reminds one of the Aorta. It has no apparent shell, and yet its shape shows that it is bounded by some membrane, the protoplasm not only has granules of various sizes along the net and in the trunk, but also two or four larger circular clear spaces near the central region of the body of the animal. He also figures *Gromia oviformis.* This is egg-shaped, with a large opening in the narrow end; the protoplasm which flows out from this aperture covers the entire surface of the shell, emitting thread-like "pseudopodia" from all parts, but these are much shorter than those which proceed more directly outwards from the mouth. In this figure we see a diatom caught by the pseudopodia, and on looking closely flint skeletons of several more are perceived within the test of the *Gromia.*

In a paper by J. D. Siddall, of Chester, in the *Quarterly Journal of Microscopic Science,* Vol. XX., N.S., there is so much of interest that we shall be excused for pretty copiously borrowing from it. He says that *Lieberkühnia Wageneri* was first found near Berlin by MM. Claparède and Lachmann, and was described and figured in their "Etudes sur les Infusoires et les Rhizopodes." The original figure (reproduced by Dr. Carpenter) is a lateral view only. It does not seem to have been observed except by its discoverers, until Siddall found it in 1878 from the shore at low-water mark near the Little Orme's Head, Colwyn Bay, associated with another rare foraminifer, *Haliphysema Tumanowiczii.*

J. D. Siddall tells us that, "in general contour *Lieberkühnia* is ovate or rounded, but the outline is constantly slowly changing by the movement of the enclosed sarcode," causing it to vary from an elongated oval or pear-shape to a nearly globular form. "The milky-white, semi-transparent, coarsely granular protoplasm, of which the body consists," is covered by a thin pellucid membrane, lined by a transparent layer of finely granulated protoplasm, the outer surface is set with a number of rod-like spicules, at various angles, not visible when coated by protoplasm in the living animal, except by the contraction of the sarcode within. "The sarcode rotates constantly within this integument, and emits at the same time from a terminal orifice, a main stem of protoplasm, from which the freely inosculating and branching pseudopodia principally arise." Pseudopodia are also numerously put forth by the coat of living sarcode which, spreading from the

aperture, completely covers the integument. "No distinct nucleus can be detected in the body, but there are several clear spaces." "These are very distinct, as they are carried along by the rotating protoplasm and are persistent in form and size." The mouth of *Lieberkühnia* is in its broader extremity in a central depression of a cross-like form.

Mr. Siddall was fortunate enough to find a fine specimen, adhering to the side of a bottle, which when transferred to a cell by a camel's hair pencil for examination under the microscope, "was found to be in the act of trying to swallow a living worm quite twice as long as itself." "Having got one end into its mouth, the *Lieberkühnia* passed a thick stream of sarcode along the worm to its farthest extremity, the creature meanwhile making feeble efforts to escape from the glairy mass. Then having got well hold of its prey, and anchored itself to the glass by an outspread network of pseudopodia, it proceeded slowly and deliberately to envelop it, partly by retracting the thick band of sarcode, and partly by advancing its own body. This process continued until the pointed end of the worm was pressed so tightly against the lower extremity of the *Lieberkühnia*, as to almost burst the integument, when finding it could engulf it no further, more sarcode flowed from the interior of the Rhizopod over the worm, until it was completely enclosed. After a couple of hours the worm was slowly ejected quite dead, a large proportion of its contents having apparently been sucked out. For some hours the animal was very active, thrusting out its pseudopodia on all sides, until they filled the field of

a three-inch objective, and it was not until six or seven hours had elapsed, that the rapidity and force of the streams of sarcode in the body and the pseudopodia of the animal were sensibly diminished."

In transferring this specimen from the bottle to the cell, two small pieces of protoplasm or sarcode were detached by the pencil-point. These pieces, when in the cell, put out pseudopodia in all directions, until no central mass was left in either. The parent *Lieberkühnia* also put out its pseudopodia, which ultimately reached those of the detached portions, when they immediately coalesced, the fragments again becoming part of the original body.

On the 22nd of August, 1879, J. D. Siddall received from Mr. Shepheard two bottles of sea water containing sponges and other low forms of animal life from the shore at low tide near Tenby; in this he discovered a new Rhizopod, of which he has given us the life history, and which he named after his friend and fellow-worker *Shepheardella.* The genus was new as well as the species, and as we have seen, has been included in the family *Gromidæ* by Brady; it was given the specific name *Tæniformis* from the Latin *tænia*, a ribbon. It is like a glass tube slightly tapering at each end to a small aperture, in length about eighty times the breadth, it is flat when in motion, and round when at rest. It has a very distinct oval nucleus, which circulates in the sarcode, as it streams up one side, and down the other, around the interior of the long cell, but instead of taking the whole circuit, it generally crosses from one stream to the other, not far from the centre of the cell. The test is flexible, transparent, and firm, and through the minute

aperture at each end, some sarcode passes and collects into a small mass. From this mass a delicate coating spreads over the test, and sometimes throws out a pseudopodium, but the great network of pseudopodia is at the two extremities of the tube, extending to a distance exceeding the whole length of the body of the animal. The circulation of the fine granular sarcode in the pseudopodia is very rapid, advancing and retiring in single, double, or even triple streams.

The length of the test varies from $\frac{1}{14}$ inch to $\frac{1}{3}$ inch.

The nucleus is an oval sac or cell possessing a very thin elastic wall, filled with fluid more transparent than the surrounding sarcode; it has an independent power of circulating motion within itself. Most specimens contain but one nucleus; one specimen had three, and in a small one none could be seen—when bent by accident, the animal straightened itself by jerks. It can crawl rapidly by its pseudopodia, and by its power of curving itself laterally.

Mr. Siddall watched several specimens from day to day, and noted the changes which took place during their breaking up; some of these results require confirmation, but among the points which appear to have been established are, the production of *Amœbæ* from the *Shepheardella*. *Amœbæ* are small masses of protoplasm, very similar to the colourless corpuscles of the blood, they constantly change their shape and put out short stout lobe-like pseudopodia; they have a small nucleus and contractile vesicle. The *Amœba* is called the Proteus animalcule—from its alteration of form. It has hitherto been assigned to a lower order than

the Foraminifera—and it is highly interesting to find it thus forming one of the transitional developments in the life history of *Shepheardella.*

Major S. R. I. Owen,* while dredging the surface of the Indian and Atlantic oceans, found Foraminifera of the genera of *Globigerina* and *Pulvinulina,* and he remarks about the Polycistinæ which accompany them:—"There are no objects in nature more brilliant in their colouring or more exquisitely delicate in their forms and structure. Some are of but one colour, crimson, yellow, or blue; sometimes two colours are found on the same individual, but always separate, and rarely if ever mixed to form green or purple. In a globular species, whose shell is made up of the most delicate fretwork, the brilliant colours of the sarcode shine through the little perforations very prettily."

With reference to the foraminiferal life on the surface of the ocean, H. B. Brady † says:—"The Foraminifera, as a rule, are not of pelagic habit. On the contrary, by far the larger proportion, probably ninety-eight or ninety-nine per cent. of known recent species, including the whole of the porcellanous and arenaceous groups, and the bulk of the hyaline forms, inhabit the sand or mud of the sea bottom, and are endowed with no swimming or floating powers. This may be regarded as a well-ascertained fact. But on the other hand, there are a certain number of forms, belonging to eight or nine genera, which it is

* *Journ. Linn. Soc.* Vol. VIII., p. 202, Vol. IX. p. 147, 1866, and January, 1867.

† H. B. Brady, "Report on the Foraminifera of the *Challenger* Expedition." Report, Vol. IX. Zoology. 4to. London. 1884.

equally certain pass their existence either in part or entirely at the surface of the ocean or in mid-water; the practical importance of these comparatively few species is due to the extraordinary abundance in which they are found, and the relatively large proportion of the entire mass of the bottom deposit which is made up of their shells."

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*** *The Italics refer to Woodcut Illustrations.*

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